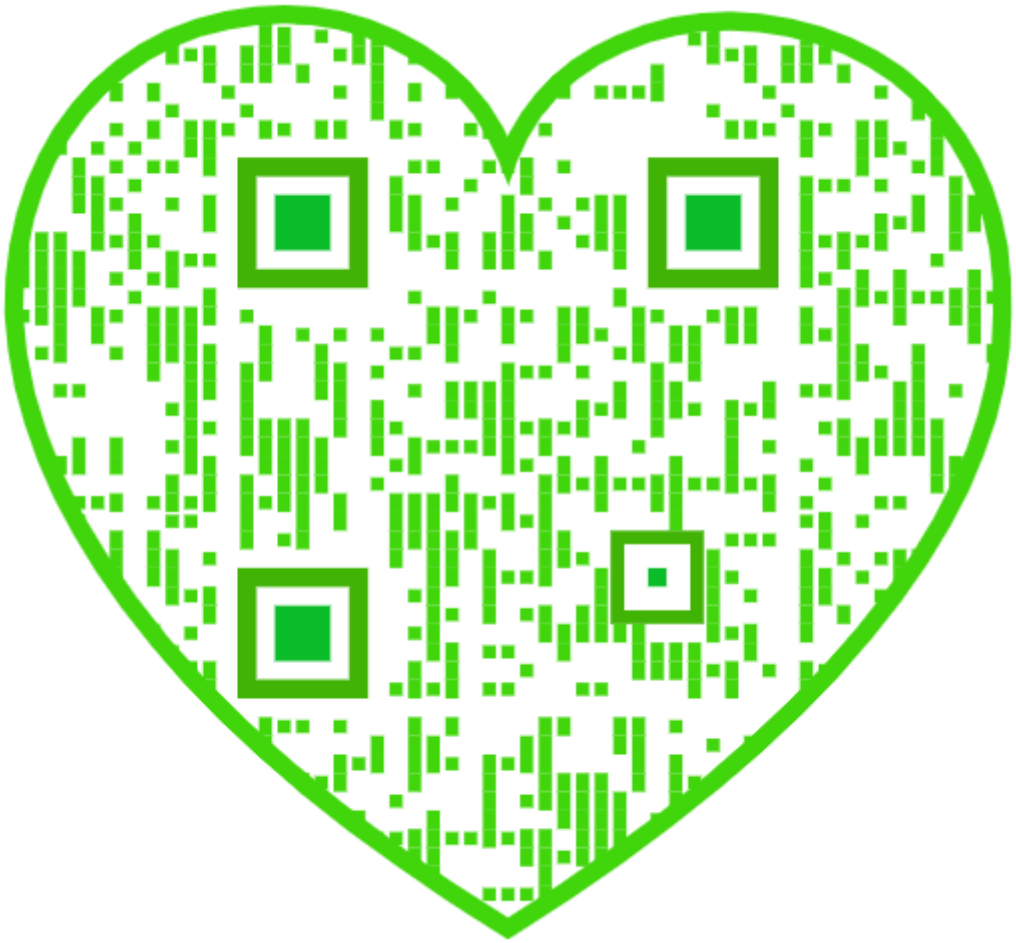

THE

MANUFACTURE OF STEEL,

BY

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TRANSLATED FROM THE FRENCH

BY

LENOX SMITH, A.M. E.M.,

WITH AN APPENDIX ON

THE BESSEMER PROCESS

IN THE UNITED STATES,

BY THE TRANSLATOR.

ILLUSTRATED BY LITHOGRAPHED DRAWINGS AND WOODCUTS.

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TRANSLATOR'S PREFACE.

THE constantly increasing importance of the already considerable steel interests of the United States has induced the translator to present this volume to the public, in the hope that the want of a careful, elaborate, and at the same time practical, investigation of the physical properties of steel, as well as of a description of the new processes and mechanical appliances for its manufacture, may thus be supplied.

A familiarity with the condition of the steel interests of other countries is of essential importance to those practically engaged in its manufacture who desire to increase their stock of technical knowledge, but who have not access to scientific periodicals, or sufficient time at their disposal to enable them to master their contents in a foreign language.

The American manufacturer cannot well afford to disregard information from reliable sources relating to iron and steel, if he desires to successfully encounter foreign competition; and the fact that this work is from the pen of Professor Grüner, who is well known in Europe as one of the most able metallurgical

authors of the present day, should of itself insure for the work a favorable reception.

From lack of accurate information, Professor Grüner has made but little mention of the extent of the Bessemer Process in the United States, and the translator has therefore appended a short memoir upon that subject.

NEW YORK, February, 1872.

THE MANUFACTURE OF STEEL.

SINCE the publication of Leplay's two excellent memoirs upon Yorkshire and the North of Europe (*Ann. des Mines*, 1843 and 1846), steel manufacture has undergone considerable modification.

Mr. Lan and myself have shown its progress as lately as 1861.* Since that time steel manufacture, far from diminishing, has yearly become more largely developed. At present it has attained colossal proportions. We are now witnessing a complete renovation of the old processes. The Exposition of the Champ de Mars has proven the importance of the products and their great variety, but the methods could not be studied there, although they should especially be understood. It is this motive which has induced me to describe the actual condition of steel manufacture, or, at least, to point out its most salient characteristics.

NATURE OF STEEL.

What is steel? This point has been much discussed for a considerable time, but no conclusion has been

État présent de la métallurgy du fer en Angleterre, 1862, part fifth; Manufacture of Steel, p. 711.

reached, because the meaning of the word was undefined. The province of steel is sometimes enlarged, sometimes unreasonably circumscribed. A certain theoretical idea is taken as a starting point, and all within the limit prescribed is denominated steel.

Experience proves that cast and wrought iron can be obtained with any ore of iron, but that the cast and wrought iron produced have various properties because of the greater or less purity of the ores, and because the methods of treatment do not all effect the elimination of foreign substances to an equal degree. According to circumstances, a metal will be obtained more or less tenacious or brittle, hard or soft, pure or impure. But none the less will the names cast and wrought iron be given to the extremes produced. For the same reason we should call every intermediate product, which is neither wrought nor cast iron, steel, whatever its degree of purity may be.

The crude cast product resulting from the reduction of the ores of iron may be called pig iron. It is an impure iron which is not malleable, at least when heated, but which may be tempered by being suddenly cooled.

The name wrought iron is given to a metal more or less refined, obtained from pig iron, or in the direct way from iron ores; it is malleable hot and cold, but not capable of being tempered.

The practical man will call every intermediate product steel, which may be tempered, but which remains malleable hot and cold when not tempered, and this

metal will be steel, whatever be the method followed to obtain it—direct extraction from the ore, partial fining of pig iron, or recarburation of wrought iron. According to this, in its properties as well as in its manufacture, steel is comprised between the limits of cast and wrought iron. It cannot even be said where steel begins or ends. It is a series which begins with the most impure black pig iron, and ends with the softest and purest wrought iron.* Cast iron passes into hard steel in becoming malleable (natural steel for wire-mills, the *Wildstahl* of the Germans), and steel, properly so called, passes into iron, giving in succession mild steel, steel of the nature of iron, steely iron, and granular iron. And these transitions are observed, not only when we compare the properties of the products and their mode of manufacture, but also their chemical composition. Doubtless it is very difficult, even impossible, to prescribe exact limits to the composition of cast irons, steels, and wrought irons. The elements are so various, and often in such slight proportion, that, in presence of the enormous preponderance of iron, their exact determination becomes impossible. But the result of the analyses made, in every case, is that the same foreign elements are found in pig irons, steels, and wrought irons, and that, after all, that which distinguishes the three products is solely, as shown long since by Karsten, the relative proportions of carbon, of which a portion is simply mingled with the iron, the remainder

* Karsten stated this in these same terms as long ago as 1823. It should never have been forgotten. (*Annales des Mines*, 1824, Vol. IX., p. 657.)

intimately combined with it, or rather in a state of solution.

We find it strange that some tenths of a per cent. of carbon can modify iron so far as to cause it to pass into steel. Rivot in his *Docimasie* appears to admit that the two substances are chemically identical, and only differ from each other in their molecular constitution—a constitution pre-existent in the ores in such a manner, that certain ores are in some sort predestined to produce steel.* Such is the case with those which have been long known under the name of *Ores of Steel.* Without wishing to discuss at present this ingenious hypothesis, I must observe that these same steel ores yield excellent irons; to obtain them it is only necessary to prolong the fining. These irons again give steel of the most superior quality, when surrounded with charcoal and heated. It appears, then, most natural to suppose, and this seems to me a result of the facts I am about to recall, that modifications so various as iron undergoes are due to the presence of carbon and divers other foreign substances. The simple changes of density, texture and tenacity, through which all metals pass, must, of course, be excepted when their crystalline condition is favored or destroyed by heat and mechanical action.

The modifications which most metals undergo through the influence of very small proportions of foreign substances have long been known, and it is not apparent why it should be otherwise for wrought iron. It is a

* Rivot, *Docimasie*, Vol. III., p. 545.

general property of metals which we cannot explain, but which must be received as a fact. We know that copper is greatly modified by traces of oxygen, sulphur, or lead; that some tenths of a per cent. of iron affect the malleability of zinc and tin. And on this head Fremy calls to our attention that 0.01 per cent. of bismuth or lead renders gold as brittle as antimony.* We also know that chromium, nickel, tungsten, titanium, etc., render wrought iron hard as well as carbon. In short, the considerable influence of these very small proportions of foreign substances cannot be denied. Now, these substances which we find combined with iron, are very much more numerous in pig irons than is generally believed. Fremy mentions carbon, silicon, phosphorus, arsenic, sulphur, potassium, sodium, calcium, magnesium, aluminium, manganese, nickel, chromium, titanium, vanadium, copper, nitrogen, etc.,† and the analyses which I shall quote will contain, in addition, some other elements, such as cobalt, molybdenum, etc. It may be said, in general, that pig irons, like all crude metals, contain a fraction of almost all the elements found in the charges which produced them.

Fremy has thought proper lately to attach very great importance to the presence of nitrogen. According to this savant, steel and the purest pig irons are combinations, not of carbon and iron alone, but *nitro-carburets*, and it is this complex radical which imparts to steel its special properties.

Fremy afterward became aware that wrought irons

* *Comptes rendus*, Vol. LII., p. 1004. † *Comptes rendus*, Vol. LII., p. 1001.

also contained nitrogen. In consequence, the radical *nitro-carburet*, if it exists, would not be a distinctive characteristic of steels. The series—*pig iron, steel, wrought iron*—would, nevertheless, exist. But nitrogen does not appear to play in these compounds the part attributed to it by Fremy. The proportion of nitrogen is very much less than was believed at first to exist. Boussingault, to whom we owe the most exact analyses on this subject, found, in a first series of assays,

0.057 per cent. of nitrogen in cast steel,
0.124 " " " " " wrought iron,*
0.007 " " " " only " cast steel,

and the same proportion in irons, and

0.022 per cent. in Krupp's steel.†

It follows from this that no fixed relation exists between the proportions of nitrogen and carbon, consequently they would not be united under the form of a special radical. We even see that in steel, properly speaking, the proportion of nitrogen does not reach one-tenth that of the carbon, while this relation is always greater in wrought irons. The presence of nitrogen appears then somewhat accidental. It appears to be owing to the property, so common to solid bodies, of condensing gas in its pores. At all events, it is now thoroughly established that nitrogen is only met with in steel in very small proportions, and if this gas is necessary to the existence of steel, it is still more necessary to wrought iron and pig metal.

* *Comptes rendus*, Vol. LII., p. 1251. † *Comptes rendus*, Vol. LIII., p. 9.

Among the other foreign elements, there are several which are not nearly as unobjectionable. Besides this, the various properties of the irons of commerce cannot really be explained, except by the presence of these elements. Their number is always considerable, and when the energetic reactions in the working of blast furnaces are taken into account, it becomes evident that even the purest pig irons are quite complex compounds. This is the result of the several analyses which I think proper to quote.

It has been long known that pig irons contain carbon and silicon, and, usually, some sulphur, phosphorus, and manganese. Karsten, in his *Metallurgy*, mentions also calcium, magnesium, and chromium, but does not venture to state anything regarding aluminium.*

The frequent occurrence of this latter body was first noticed by Schafhaütl, about 1840; at present the fact is well established, for we even find aluminium in pig metals obtained from charges containing but little alumina. The tri-silicate slags of the cannon foundry of Finspong, in Sweden, only contain 3 per cent. of alumina, and these cast irons are of the following composition, according to Eckmann and Eggertz: †

Metallic Iron.....	93.660
Aluminium.....	0.173
Manganese.....	0.190
Calcium and Magnesium...	traces

* French edition, 1830, Vol. I., p. 252.

† Pamphlet published upon Finspong on the occasion of the Universal Exposition in 1867.

Copper	0.005	
Silicon	0.946	
Phosphorus	0.050	
Sulphur	0.120	
Carbon	3.920	Of which 2.17 is graphite.
	99.064	

According to the annals of the Bureau of Iron, of Stockholm, Durocher had already published, in 1856, several analyses of these same pig irons from Finspong, all of which mention some aluminium, calcium, and magnesium.* A Swedish pig iron was exhibited at the Exposition, containing, according to Eggertz, 0.26 per cent. of calcium and 0.16 per cent. of aluminium.† If the numerous analyses published by Berthier do not show any of these earthy metals in pig irons it is because no importance is attached to them, and that even the search for these elements was purposely neglected. But it is evident that, by smelting any ore containing alumina, a pig iron more or less rich in aluminium would be obtained. Under this head may be quoted the gray pig irons produced from our granular ore, and the black pig irons of Scotland, smelted from argillaceous *black band* ores, in a very hot working of the blast furnace.

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* *Annales des Mines*, 3d series, Vol. IX, p. 420. Durocher was wrong, in thinking that the conclusion could be drawn from one of these analyses that sulphur increases the tenacity of gray irons, and that irons containing from 1 per cent. to 2 per cent. of sulphur, are made purposely at Finspong. They really seek to reduce the proportion to less than 0.2 per cent. (Page 11 of Rinman's memoir above quoted.)

† Some information concerning the wrought irons and steels of Sweden, by L. Rinman, 1867, p. 25.

The presence of so great a number of foreign elements renders a complete analysis of pig irons one of the most complicated operations of inorganic chemistry, and notwithstanding this, the search for any of these substances cannot be omitted under the pretext that it exerts no influence upon the quality of the irons and steels, resulting from fining these pig metals.

The last volume of the *Archives de Karsten* (vol. xxv, p. 235, 1853), mentions two analyses which suffice to prove the complicated composition of pig irons. The irons are from Vekerhagen and Holtzhausen, in Hesse Cassel. They were smelted with hot blast and charcoal from Tertiary limonites. The first answered for foundry purposes; it was very fluid, filled the moulds well, but whitened in thin layers, and then became brittle. Its specific gravity was only 6.668. The second, that of Holtzhausen, was slightly mottled, softer, more tenacious than the former, but like it of a dull shade in fresh fractures, which, as is known, denotes a great proportion of foreign substances. For the same reason its specific gravity was also low, being only 6.799. Both irons sustained great waste in fining. Solution was effected for the principal analysis by a mixture of hydrochloric acid and chlorate of potash, and the residue was separately examined. The results are as follows:

	VEKERHAGEN PIG.	HOLTZHAUSEN PIG.
Total Carbon	2.876	2.215
Silicon	2.748	1.981
Sulphur	0.207	0.083
Arsenic	0.139	traces
Phosphorus	0.421	0.068
Calcium	traces	0.352
Magnesium	0.146	0.895
Aluminium	0.032	0.272
Molybdenum	0.184	0.014
Chromium	0.080	0.051
Vanadium	0.004	traces
Manganese	8.953	2.814
Metallic Iron	83.383	30.718
	99.173	99.463

In both irons the insoluble residue afforded the greater part of the manganese and silicon, viz.:

Iron from Vekerhagen { Silicon 2.668
Manganese 6.871

Iron from Holtzhausen { Silicon 1.345
Manganese 2.814

The insoluble residue of the latter contained in addition 0.167 per cent. of aluminium, and 0.133 per cent. of metallic iron. It is apparent that in gray pig irons, rich in manganese, the silicon seems to be chiefly united with the latter substance. And we know, in fact, from the investigations of Brunner and Wöhler, that manganese combines readily with 11–12 per cent. of silicon by fusion.

These analyses prove that gray pig irons often contain above 10 per cent. of foreign substances, and that almost always their number is considerable. It is certainly true of most black irons possessing little tenacity, which result

from a very hot working of the blast furnace. But even white pig irons, obtained from spathic ores, classed generally among the pure products, have also a very complex composition. Below are two analyses by the skillful chemist Fresenius. The first is of spiegel pig iron (Spiegeleisen) from Müsen, smelted from the ores of Stahlberg, in Siegen,* with charcoal. The specific gravity of the metal varies from 7.60 to 7.66.

Total Carbon	4.323
Silicon	0.997
Nitrogen	0.014
Sulphur	0.014
Phosphorus	0.059
Arsenic	0.007
Antimony	0.004
Sodium and Lithium	traces
Potassium	0.063
Calcium	0.091
Magnesium	0.045
Titanium	0.006
Aluminium	0.077
Copper	0.066
Cobalt	traces
Nickel	0.016
Manganese	10.707
Metallic Iron	82.860
Intermingled Slags	0.665
Total	100.014

The second analysis is of a coke spiegel pig iron,

* *État actuel de la métallurgie du fer dans le pays de Siegen*, by Jordan, p. 36

smelted in 1864 at the works of St. Louis (Marseilles), from a mixture of iron and manganese ores. The analysis was made at the request of Mr. Jordan, then the manager of the works in question, and we are indebted to him for communicating the results obtained. The iron was white, but showed some gray specks:

Combined Carbon	4.040
Graphite	0.126
Silicon	0.584
Sulphur	0.035
Phosphorus	0.090
Arsenic	0.032
Antimony	0.026
Magnesium	0.058
Aluminium	0.068
Copper	0.046
Manganese	5.920
Metallic Iron	88.781
Total	99.806

Traces of calcium, cobalt, nickel, and nitrogen were found besides.

Among the purest pig irons we may mention that of Eisenertz in Styria, smelted from spathic ores, with charcoal in a cold working of the blast furnace. The white cavernous pig metal obtained under these conditions is composed, according to Dr. Percy,* of

Combined Carbon	3.79
Silicon	0.34
Sulphur	0.02

* Percy's Metallurgy, Iron and Steel, p. 536.

Phosphorus	0.07
Manganese	1.06
Calcium	0.05
Magnesium	0.02
Metallic Iron	94.57
Total	99.92

It is apparent, even in the case of a slow reduction, that the iron may retain some silicon and some tenths of a per cent. of the earthy metals. All things considered, then, the preceding analyses, even admitting that they do not represent the exact composition of the irons examined, nevertheless support the general conclusion stated above, *that crude wrought iron retains a part of all the elements present together in the blast furnace.* But now, what becomes of these substances in working for steel?

If the steel be obtained by fining, it is evident *a priori*, and analysis proves it, that only those elements can be entirely eliminated which are at the same time readily oxydized and have a slight affinity for iron. Of this number are manganese, calcium, magnesium, etc. On the other hand, aluminium, which is not readily oxydized, according to Deville, and which is intimately combined with the iron, must be more difficult to remove completely, and, in fact, certain cast steels contain traces of this substance. The greater part of ordinary steels retain, besides, some sulphur, phosphorus, and silicon. As to the copper in pig irons, it is found in greater part in the steels and wrought irons. It is sufficient to recall the

researches of Lan in the Rivois process,* and those of Bromeis on the iron of Magdesprung in the Hartz.† The good natural steel of Siegen always contains, in like manner, 0.1—0.16 per cent. of copper, according to Stengel, and 0.2—0.4 per cent. of silicon.‡

In a Krupp cast steel for cannons, obtained probably by simple fusion of a mixture of pig and wrought iron from Siegen in a crucible, Mr. Abel, Manager of the Chemical Office of the London War Department, found the following elements :§

Carbon	1.18
Silicon	0.33
Phosphorus	0.02
Sulphur	0.00
Cobalt and Nickel	0.12
Copper	0.30
Manganese	traces
Metallic Iron	98.05
Total	100.00

In Indian Wootz Henry found some silicon, sulphur, and arsenic.

Philipps, the engineer of mines, has proved the existence of silicon, cobalt, and nickel in all the cast steels made by Trinquet at St. Etienne. The greater part were obtained by melting the iron from the catalan forges of the Pyrenees after cementation ; some others by combining pure pig and wrought iron in crucibles.‖ It follows

* *Annales des Mines*, Vol. XV., p. 103, 5th series.
† Rammelsberg's *Métallurgie Chimique*, p. 161.
‡ *Archives de Karsten*, Vol. IX. and X.
§ The Artisan, December, 1856, and Percy's Metallurgy.
‖ *Annales des Mines*, 1848, Vol. XIV., p. 326.

from this that the wrought iron must contain nickel and cobalt before the cementation.

Finally, according to Parry, the skillful chemist of that vast establishment, the puddled steel of Ebbw Vale contains: *

Carbon	0.501
Silicon	0.106
Sulphur	0.002
Phosphorus	0.096
Manganese	0.144
Metallic Iron	99.151
Total	100.000

We have just shown that wrought iron, like steel, quite frequently contains copper, cobalt, and nickel, and on the other hand, according to Karsten, it has long been known that there is carbon, silicon, sulphur, and phosphorus in all wrought iron. In reality steel and wrought iron are compounds almost as complex as pig irons. The proportions only are less. We find, with very few exceptions, traces at least of all the elements of which pig irons are composed, and we believe that each of these elements must modify to a greater or less extent the especial properties of pig iron, wrought iron, and steel.

Now, among these elements there is one which should especially occupy our attention—carbon. It is, in fact, easy to show, by examining the Bessemer steels made in Sweden and Austria, that hardness and the susceptibility of being tempered depend essentially upon the proportion of carbon held in solution.

* Percy's Metallurgy, p. 797.

In Sweden nine grades of Bessemer* steel are distinguished according to their hardness, estimated by the tempering power. They are designated by the numbers 1, 1½, 2, 2½,.....as high as 5, in passing from the hardest to the softest, and, at the works of Siljanfors, analysis has shown very nearly the following proportions of carbon:

No. 1	2.00 % Carbon
" 1½	1.75 % "
" 2	1.50 % "
" 2½	1.25 % "
" 3	1.00 % "
" 3½	0.75 % "
" 4	0.50 % "
" 4½	0.25 % "
" 5	0.05 % "

No. 1. Links white pig metal with the hardest steel; it may, with difficulty, be forged, and does not weld.

No. 1½. Forges tolerably well, but does not weld.

No. 2. Forges well, but does not weld.

No. 2½. Forges well and commences to weld, although with difficulty.

No. 3. Forges very well, and may be welded in the hands of a skillful workman. It is hard steel.

No. 3½. Forges very well and welds readily. It is ordinary steel.

No. 4. Both forges and welds readily. It is soft steel.

No. 4½. Forges and welds perfectly, but has slight tempering power. It is hard, or granular iron.

* Boman's German memoir, *Sur le procède Bessemer en Suède.*

No. 5. Forges and welds perfectly, but has no tempering power. It is cast wrought iron, or homogeneous metal.

It must now be remarked, that the proportions of carbon which I have quoted, have no absolute value as regards the tempering power and the facility with which the irons may be welded or drawn out. The purer a steel is, the greater may be its proportion of carbon without destroying its welding and forging power. The greater part of foreign substances, excepting special metals, such as tungsten, titanium, nickel, etc., render steel short and destroy its welding power when the carbon exceeds a certain limit. Let us also observe that, all things being equal, the limit in question is lower according as the foreign substances are more abundant. This being the case, Bessemer steels made in France, and especially in England, must in general contain less carbon than Swedish steels. They are, in fact, made from pig iron of less purity ; and we know that Bessemer steel, or rather Bessemer metal, in England rarely contains carbon enough to admit of being tempered.

When the proportion of carbon is increased the product becomes more or less short.

In Austria, as in Sweden, where very pure pig irons are treated in the Bessemer process, superior products are likewise obtained. Tunner, the eminent metallurgist of Léoben, has adopted a system of classification slightly differing from the Swedish. He has, however, omitted the two first Swedish numbers, which belong rather to

white pig iron, and has replaced the half numbers by entire numbers increasing from 1 to 7.

According to him the theoretical classification is as follows :*

No. 1. Containing 1.5 per cent. of carbon, is malleable but yet not weldable steel. It corresponds to No. 2 of the Swedish scale.

No. 2. Containing 1.25 per cent. of carbon, is malleable steel, but difficult to weld.

No. 3. Containing 1.00 per cent. of carbon, is very malleable steel, which may be welded by a skillful workman. It is hard steel.

No. 4. Containing 0.75 per cent. of carbon, is very malleable steel, easily welded. It is ordinary steel.

No. 5. Containing 0.50 per cent. of carbon, is, at the same time, very malleable and very easily welded. It is mild steel.

No. 6. Containing 0.25 per cent. of carbon. It is granular iron, which is tempered with difficulty.

No. 7. Containing 0.05 per cent. of carbon, is homogeneous iron, which cannot be tempered.

When the fining is carried too far, a softer metal than No. 7 is obtained. It is *short*, without tenacity. It is the *burnt iron* of the blacksmiths ; according to Fremy, an oxydized and not a nitrogenized iron.

The theoretical classification has been verified at the works of Heft, in Carinthia.

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* *Oestreichische Zeitschrift für Berg und Hüttenwesen*, year 1865, p. 153.

Below are given the proportions of carbon obtained by analysis:

	ACCORDING TO TUNNER'S MEMOIR ABOVE CITED.	ACCORDING TO NOTES TAKEN AT THE EXPOSITION.*
No. 2.....	1.35 per cent.	
No. 3.....	1.15 " "	1.00 to 1.10 per cent.
No. 4.....	0.85 " "	0.75 to 0.85 " "
No. 5.....	0.72 " "	0.42 " "
No. 6.....	0.53 " "	0.25 " "
No. 7.....	0.11 " "	" " "

* A similar series of Bessemer steel from Fagersta, in Sweden, containing from 0.10 to 1.30 per cent. of carbon, was also exhibited at the Exposition.

At the imperial works at Neuberg, in Styria, the proportions of carbon, according to a statement published at the time of the Exposition, are the following:

NUMBERS OF HARDNESS.	PROPORTIONS OF CARBON.	OBSERVATIONS.
No. 1...	1.58 to 1.38 per cent.	Cannot be welded, and is rarely used.
No. 2...	1.38 " 1.12 " "	
No. 3...	1.12 " 0.88 " "	Welds easily, used for bitts, chisels, etc.
No. 4...	0.88 " 0.62 " "	Used for cutting-tools, files, etc.
No. 5...	0.62 " 0.38 " "	Mild steel for tyres, etc.
No. 6...	0.38 " 0.15 " "	Tempers slightly; steel for boiler-plate and axles.
No. 7...	0.15 " 0.05 " "	Does not temper. Steel for pieces of machinery.

These results show that 0.25 per cent. of carbon, more or less, suffice to make steel pass from one grade to another. They fully confirm the earlier theory, according to which, all things being equal, the grade of a steel is otherwise nearly relative to the proportion of carbon. I say, *all things being otherwise equal*, for I must repeat that other elements may increase or retard the facility with which the metal welds, increase or diminish its hardness after tempering, and render it more or less short or tenacious, so that the proportions above set forth have really only a relative value. Notwithstanding

this, we may certainly say that *the qualities of steel depend chiefly upon the proportion of carbon.*

In Sweden and Austria, a very great importance is justly attached to the classification of Bessemer steels. If the new product is to be commercially accepted, the hard steels for cutting-instruments (Nos. 2 and 3 of the Austrian scale), should be carefully distinguished from medium steels for springs, pieces of machinery, and tyres (Nos. 4 and 5), and these again should not be confounded with the extra soft steel (*homogeneous irons*), used for sheet-iron, axles, gun-barrels, etc. (Nos. 6 and 7). In both these countries, each bar is marked with the number of the class to which it belongs, before delivering it to the consumer. It would certainly be of utility, if a like custom prevailed in English and French works.

In the Austrian establishments, Nos. 1 and 7 are rarely made, the first, because its extreme hardness has a tendency to make it short; the latter, because of its diminished tenacity.

The tenacity varies little* between Nos. 2 and 6, but the elongation which the bar undergoes before breaking is greater as the proportion of carbon is less. In the Swedish section of the Exposition were a number of cylindrical bars tested in this way. On the side of each bar the breaking weight was marked, the relation between

* According to the already quoted note concerning Neuberg, the absolute tenacity would seem to decrease regularly with the proportion of carbon. This is not perfectly confirmed, however, by the observations made in Sweden and elsewhere. Still, steels containing little carbon are, generally, the least tenacious.

the sections of rupture and the original section, and the proportion of carbon in the specimen tested.

The proportions appear to have been determined by the Eggertz method, which I shall explain at the end of this treatise. As this method appears to me to possess all desirable accuracy, I think it proper to quote the figures. The steels are from the works of Fagersta, near Neuberg.

A steel containing 1.2 per cent. of carbon broke without elongation. The softer steels gave the following results:

PROPORTION OF CARBON.	BREAKING WEIGHT.		RELATION BETWEEN THE ELONGATED AND ORIGINAL SECTIONS.
	Per square millimetre.	Per square inch.	
1.00 per cent.	95–109 kilog.	135131–155042 lbs.	0.91–0.95
0.70 "	86–102 "	122330–145105.5 "	0.80–0.90
0.45 "	90–103 "	128021–146505.6 "	0.68
0.35 "	138.8 "	190334 "	0.36

A still softer steel, a kind of homogeneous iron, containing from 0.1 to 0.3 per cent. of carbon, is employed at Fagersta for gun-barrels. With a bursting charge the metal expands and tears without flying to pieces.

The same establishment exhibited an extra hard steel containing 1.50 per cent. of carbon, with which steel containing 1.00 per cent. of carbon may be bored, even when tempered.

At Neuberg, steel No. 3 elongates 5.00 per cent. before rupture. No. 4 elongates 5.00 to 10.00 per cent., No. 5, 10.00 to 20.00 per cent., No. 6, 20.00 to 25.00 per cent., and No. 7, 20.00 to 30.00 per cent.

Let us also state that, according to Vickers of Shef-

field, the tenacity of steels diminishes as soon as the proportion of carbon exceeds 1.25 per cent. (*Journal de Léoben*, by Tunner, Vol. XV., p. 300.)

In resume, then, it results from all which precedes that the irons, steels, and pig metals of commerce are analogous compounds of iron and carbon always combined with other foreign substances; that the peculiar properties of these different irons are especially dependent upon their purity and the proportions of carbon in combination; that, in fact, a continuous chain links soft irons containing a minimum of carbon with steels, and the latter again with pig irons.

It has long been known that all the carbon in white irons and tempered steels is really combined, or held in solution, while in gray irons and steels not tempered, a portion of the carbon remains separated in the form of graphite.

Caron has recently demonstrated that hammering steels hot produces the same effect as tempering, and therefrom concludes that hammering, like tempering, causes a combination of the carbon and iron.* I should rather judge that hammering, like tempering, prevents the separation of the two substances already combined. It is known from the phenomena which take place in blast furnaces and in cementation furnaces, that iron holds all the more carbon in solution, when the temperature is more elevated and longer sustained, while by slow cooling the excess of carbon is again separated. But in

* *Comptes rendus*, Vol. LVI., p. 46 and 212.

soft bodies a certain time is necessary for the movement of the molecules.

If, then, the cooling is sudden, the carbon cannot separate ; a sort of supersaturation is produced. Hammering produces the same effect, but rather, in my opinion, because it prevents the independent crystallization of the iron and carbon, by bringing together, and continuously intermingling, the molecules of the two bodies. This proves that tempering and hammering cannot act in the same manner ; that hammering, as we know, increases the density, while tempering diminishes it. Caron has, in fact, discovered this very curious circumstance, that a bar of steel becomes shorter under successive temperings, while it increases in size, laterally, in such a manner, that there actually is an increase of volume.

METHODS OF MANUFACTURE.

Steel may be obtained by two methods : on the one hand, by *direct fining*, in the same manner as wrought iron ; on the other, by *recarburation* of this wrought iron. With a given pig iron, the latter method will, of necessity, give a purer product than the former. The foreign bodies will be more completely removed by continuing the fining till wrought iron is reached. The process, however, will be more expensive, because the cost of recarburation is added to that of fining. It is nevertheless applied in two very different cases, which correspond exactly to the two extreme instances in which the *Extra*

Process is employed in the treatment of copper in England.

In the first place, we resort to it when we wish to produce *very superior* steel from pig metals of the first quality. Thus the Dannemora pig iron is converted into wrought iron, which is then cemented in England for superior steel.

In the second place, we employ it when we wish to obtain *common* steel from *ordinary* pig metals, which, owing to the excess of foreign substances, can be fined only for wrought iron. Such are the English pig irons, smelted from the ores of the coal formation, which are converted into cast steel for rails, by the application to puddled iron of the method of recarburation, invented by Parry, of Ebbw Vale, or, more simply, by fusion in crucibles, with the addition of charcoal or pure pig iron.

But before occupying ourselves with the *indirect* method, let us first see in what *direct fining* consists.

In fining pig metal for iron or steel, we may pursue three different courses.

First: We may operate upon *solid* pig iron at a more or less elevated temperature, but without fusion. When the decarburation is complete, the product is *ordinary malleable* cast iron, and *malleable steely* cast iron (*Glühstahl* of the Germans) when the fining is partial.

Second: We may operate upon *softened* or *fluid* pig iron so as to obtain a *solid* product which, according to the degree of decarburation, will be a wrought iron or natural steel; that is to say, the wrought iron, or steel of the

low hearth and the *puddled* iron or steel of the reverberatory. Instead of fining the pig iron proper, the sponges obtained directly from the ore by the Catalan and Chenot methods may also be treated in the same manner.

Third : Finally, we may operate upon molten pig iron at a temperature so high that the product remains *fluid.* This result is obtained by the so-called processes of *reaction* and *Bessemer.* According to the degree of the decarburation, ordinary cast steel or cast wrought iron will be produced ; the latter is called of late wrought iron or *homogeneous* metal. This name appears to have been adopted, according to Percy, in the first instance, by Joseph Bennett Howell, of Sheffield, in his patent of 1856. Finally, we may decarburize still less, and obtain a product intermediate between steel and cast iron. It is the *Feineisen*, or *Reineisen*, and the *Hartguss* of the Germans. I will adopt the term *refined pig iron* for these mixed products.

Let us glance in review at these different processes, pausing at those which present any new peculiarities.

I.

Direct Fining without Fusion.

Direct fining without fusion consists in slow oxydation of the carbon of the pig iron by roasting, or by some solid oxydizing agents. The latter especially are used, and this decarburation in closed vessels by oxydizing cementation we owe to Réaumur, who recommends softening

pig iron by heating it enveloped in burnt iron, then called *safran de mars*.*

This is evidently the least perfect of the three methods, for, if the foreign elements could all be oxydized, only those whose oxyds are volatile could really be eliminated—carbon, sulphur, and arsenic. It can only be applied then to very pure pig irons, and as graphite is difficult to oxydize, they must be white, or rendered so by recasting. Charcoal irons, made from the red hematites in the north of England, are chiefly used. White pig irons smelted from spathic ores may also be employed, but it is necessary that they be freed in great measure from manganese, which renders iron and steel brittle, as Bréant † long since proved, and Caron ‡ recently confirmed, by remelting (a sort of Styrian refining).

The following analysis by Dr. Miller, quoted by Percy,§ proves that the combined carbon is oxydized almost exclusively.

COMPOSITION OF THE PIG IRON BEFORE FINING.	COMPOSITION OF THE MALLEABLE CAST IRON.
Combined Carbon.....2.217 %	0.434 %
Graphite.....0.583 %	0.446 %
Silicon.....0.951 %	0.409 %
Sulphur.....0.015 %	0.000 %
Aluminium and Phosphorus.....traces	traces

We see that the sulphur is completely eliminated, and it would appear that a portion of the silicon is likewise

* Réaumur. *Art de fabriquer l'acier*, 1722, p. 472.
† *Annales des mines*, 1st series, 1824, Vol. IX., p. 325.
‡ *Comptes rendus*, Vol. LVI,. p. 828.
§ Percy's Metallurgy, Vol. II., p. 111.

removed, but the silicon which has disappeared ought certainly to exist in the softened product as silica or silicate of iron. Tunner also now affirms that the silicon is partly eliminated, but I avow that I have some difficulty in believing the fact possible if there is an actual elimination, and not simply a partial oxydation of the silicon.*

I will again quote the following analysis of a malleable cast iron made at St. Étienne. We are indebted for it to Philipps,† the engineer of mines.

Carbon	0.54 per cent.
Silicon	0.44 " "

Sulphur, etc., were not sought for.

Malleable cast iron may be forged, but is a product possessing little tenacity and density, and in the presence of 0.40 to 0.50 per cent. of silicon, as shown in the two analyses just quoted, this is not surprising.

Steely malleable cast iron differs from malleable cast iron proper only in the higher proportion of carbon which remains in it. It requires a pig iron of still greater purity, a properly fined white iron. The metal to which we now turn our attention, the *Glühstahl* of the Germans, has been manufactured chiefly by De Mayr of Léoben (Styria). It can be forged, and files have been made of it, but the product is nevertheless short. Owing to the low price of Bessemer steel, Mr. De Mayr has lately discontinued the

* *Stabeisin und Stahlbereitung*, Vol. II., p. 49

† *Annales des mines*, 1848, Vol. XIV., p. 327.

manufacture, and it may be said that the method of fining by oxydizing cementation has no longer any reason to exist.

II.

Fining Fluid Pig Iron with Solid Fined Products.

This is the usual method of fining for wrought iron and steel.

Iron and forge steel are obtained in the low hearth with charcoal.

In the reverberatory, iron and puddled steel are made.

These are familiar modes of treatment. I do not propose to describe them again; I will only remark, that owing to the increasing cost of charcoal, the low price of wrought iron, and the perfection to which puddling has been brought, working in the low hearth is becoming more rare, except in countries like the Alps, Ural mountains, and Sweden, where the ores are very pure and wood still abundant. Everywhere else puddling is gradually replacing it, but the reverberatory, as well as the low hearth, gives impure products. In both cases blooms are produced, from which all the scoria cannot be expelled. They are sponges steeped with silicates. A solution of continuity exists between the particles of iron, and, consequently, a lack of cohesion and tenacity more apparent as the blooms are larger.*

* The exceptionally good quality of wrought iron removed by attachment in certain German forges is owing to the smallness of the samples and the high temperature, which favors the fusion of the scoriaceous particles.

The small weight of the blooms is a grave defect in the method in question. Large pieces of wrought iron are only to be had by uniting together a number of bars by welding. Now at the centre of the piles this welding is always imperfect.

Another difficulty is consequent upon this. When a large piece of wrought iron is kept hot without being drawn out, it tends to assume a crystalline state.

We are aware of the semi-fluidity of soft solid bodies from Tresca's experiments. The molecules of iron are mobile at this temperature, and may be grouped in regular crystals. This is what takes place at the centre of every large mass which cools slowly. We cannot control this tendency to crystallization except by sudden chilling, but the temper which the exterior of the mass receives must be destroyed by gentle reheating. Bomb-proof plates are prepared in this manner, and all large forgings should be thus treated.

In this respect the Exposition was remarkable; specimens weighing 15,000—30,000 kilogrammes (33,000—66,000 pounds), from Petin, Gaudet & Co., Marel Brothers, Lacombe & Russéry, Creusot, etc., were exhibited. As regards the quality of wrought irons and the weight of the masses handled, the working of puddled iron has made immense progress. But a fundamental defect still exists, and is inherent in the method itself. We cannot have tenacious and pure wrought irons and steels, a really homogeneous mass, when the product fined is not liquid and cannot be cast in the form of an *ingot*. Now, this is

the especial characteristic of the third method, and which makes it so valuable. It is the future of iron metallurgy, and the incentive which leads us to turn our particular attention to it. But first, let us mention some experiments, whose results have not been, and could not be, successful.

Several metallurgists have thought that instead of smelting ores in a blast furnace, it would be better to simply reduce them to the condition of *soft* or *carburized sponge.*

They hoped to obtain purer products and consume less fuel by operating at a lower temperature. They were completely deceived. When the sponges are made, instead of cast iron we have blooms of less purity, since they contain, besides the usual cinder, the earthy substances in the ore. And if the sponges are melted in crucibles, instead of forging them directly in the form of blooms, we shall have a homogeneous product, but it will be iron or crude steel of inferior quality unless the iron sponge undergoes fining like pig metal. This was done with the Chenot sponges at the works of Baracaldo in Spain, near Bilbao. But they thought, besides, to reduce the ore by a simple mixture of combustible gases, and did not think that if the oxyds of carbon and hydrogen would reduce the oxyd of iron, the carbonic acid and steam would oxydize the metallic iron, so that, to produce wrought iron by gases alone it is necessary to use a great excess of oxyd of carbon and hydrogen, or introduce solid carbon, as in blast furnaces,

in order to effect the constant reduction of the gases oxydized by the action of the oxyd of iron. It is well to remember, on this subject, that, according to Debray, peroxyd of iron cannot be reduced to the condition of metallic iron with less than four equivalents of hydrogen for one of steam, while, if the proportion of hydrogen is less, it only returns to the state of black protoxyd. It is the same as a mixture of $CO_2 + CO$; to obtain wrought iron there must be more than one equivalent of carbonic oxyd per equivalent of carbonic acid.* In the direct methods whose object is the abolition of blast furnaces, the addition of coal mixed with the ore cannot be avoided; and it is this which destroys all profit in the processes invented by Chenot in France, Renton in America, Gurlt in Germany, etc.

III.

Fining Fluid Pig Iron with Fluid Fined Products.

Pig iron is fined at a temperature sufficiently high to obtain cast steel or wrought iron, called *homogeneous* metal, as its purified products. The scorias, being fluid, separate completely from the metallic product, as in the blast furnace. Homogeneous ingots result, which, for that reason, are much more tenacious than the blooms obtained by the preceding method. This is the advan-

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* *Comptes rendus*, Vol. XLV., p. 1018.

tage of the processes remaining to be treated of, and the only secret of their superiority. This incontestable superiority also contains the germ of a complete transformation in the working of iron.

This third method of fining comprises several processes. The most remarkable, and, at present at least, the most widely known, is the *Bessemer* process. As differing from it we may quote the *Bérard* process. The fining is essentially effected, in both cases, by the oxygen of the air.

But we may also fine by means of solid agents, such as iron and oxyd of iron; this is the method *by reaction*, so called, already alluded to by Réaumur, and even by Vanaccio for obtaining *forge steel*, and afterward recommended by Clouet, Mushet, Hassenfratz, Uchatius, and others, for making *cast steel*. The fusion was then effected in crucibles, as in establishments where blister steel is melted, whereas at present a reverberatory is employed. Hassenfratz mentions the latter furnace as early as 1812. Heath, John Davie Stirling, and Bessemer, have tried it in England, the former in 1845, the two latter in 1854 and 1855. Later, in 1858, Sudre and Petin and Gaudet employed it, for a very short time, in France; the process, however, did not become practical until after the prolonged experiments of Alexandre in the imperial foundries at Villeneuve and Ruelle, in 1861 and 1862, and especially through the exertions of Martin since 1865, at his works at Sireuil. Let us now treat somewhat of each of these processes.

Bessemer Process.

Bessemer Process in France. The Bessemer process is at present widely disseminated throughout all countries, as the Universal Exposition has shown. In France it is regularly conducted at Imphy, Assailly, Terre Noire, and Mutterhausen: at several other establishments as an experiment. The experience gained confirms generally the results attained in my two memoirs of 1861 and 1862. It has been everywhere proved that pure pig iron is necessary to obtain good products. The fining is successful on this condition only. The expectations of Fremy to the contrary have thus far not been realized. The most suitable irons for Bessemer steel are obtained in France from the ores of the Pyrenees (massive ores of Canigou and Vicdessos), and from the magnetic ores of Mokta-el-Hadid (Bône), and from the island of Sardinia. The spathic ores of the Alps would be equally suitable, and probably also the Périgord hematites containing manganese and certain granular ores from central France.

The ores of the Pyrenees are brown hematites and spathic ores more or less decomposed. They are worked in the blast furnaces of Ria, La Nouvelle, Berdoulet, Pamiers, etc. Those from Bône and the island of Sardinia resemble Swedish ores. They yield 60.–65. per cent. of pig iron containing a small proportion of manganese. At some establishments the proportion of manganese is augmented by adding ore from Garrucha (South

of Spain), or even oxyd of manganese, to the charge in the furnace.

The magnetic oxyd of the island of Sardinia is smelted at Givors, in the coke furnaces of the Petin-Gaudet Company. The ore of Mokta is worked at Terre Noire, Saint Louis, Vienna, Givors (Rochette blast furnaces), Chasse, Creusot, etc., and it is owing to this ore that Creusot now produces irons of superior quality with raw coal.

The English method is used universally in the Bessemer works of France ; that is to say, the movable converter with the addition of pure spiegel pig iron, for recarburizing the burnt iron. Success is only attained by using gray irons. When white pig iron containing little silicon is treated, the immediate reaction of the oxyd of iron upon the carbon and the separation of carbonic oxyd which ensues, prevents the mass from being heated. It remains viscous, and this want of fluidity induces explosion. On the other hand, when the pig iron contains silicon and a small proportion of manganese, the mass is hotter, because at the outset solid oxydized products only are formed. That the operation be successful it is necessary that the first period, that of *scorification* or *refining*, be relatively of long duration. Jordan observes, in his interesting memoir on the iron works of Siegen, that an excess of manganese also causes explosions, and that gray iron should not contain above two per cent.*

**État de la métallurgie du fer dans le pays de Siegen*, 1864, p. 32.—Upon the subject of these explosions Jordan says: "They are possibly owing to the facility with which manganese would absorb oxygen at a certain temperature,

The same observation was made in France, except that the limit of two per cent. was not absolute, it should vary with the relative proportions of silicon and carbon. We know that, all things being equal, a pig iron contains less silicon and often more carbon, according as the charge in the blast furnace is richer in manganese. In all cases the injurious influence of an excess of manganese upon the working of the Bessemer process has been universally proved.

The Bessemer converters in France, as in England, have, up to the present time, been charged with iron remelted in a reverberatory. The works of Terre Noire afford the first instance of deviation from this custom, imitating in this the practice previously adopted in Sweden and Austria in the treatment of charcoal irons. The works of Terre Noire possess two converters of 3,000—4,000 kilogrammes capacity (6,600—8,800 pounds) each. They blow several times a day. They fine directly almost the entire product of one blast furnace.* When the iron is gray the operations usually last from 20—25 minutes; when the pig iron is whitened at the edges it lasts 15 minutes only. Explosions are then frequent,

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and part with it at a lower temperature." This explanation seems to me scarcely admissible. The explosions result rather from the high proportion of carbon which manganese irons always contain, and probably also from the refractory condition of the metallic manganese, which renders pig irons less fluid. Finally, it must not be forgotten that pig irons rich in manganese contain little silicon, a circumstance which facilitates the reaction of the oxyds upon the carbon.

*The company is about to enlarge its Bessemer shop at Terre Noire, and establish another at Bességes.

because the metal remains slightly cold. The precise results of this treatment are not known to me, but in all cases at least 80 per cent. merchantable products are obtained; and what proves the economy of the process is that these works made a tender to the Paris, Lyons, and Marseilles Railway for an order of 22,000 tons Vignoles rails of Bessemer metal, at 315 francs ($58.56)* per ton, at the works.

At this establishment the rail steel may be slightly tempered; the plate steel does not take a temper, and rather belongs to the category of homogeneous irons. The former corresponds to Nos. 5—6 of Tunner's scale; the latter, to Nos. 6—7. According to experiments of tensile strength made at Terre Noire, the ordinary Bessemer steel (No. 5) breaks with a strain of 70 kilogrammes per square millimetre (99,554 pounds per square inch), and the soft plate steel with a strain of 55—60 kilogrammes (78,263—85,360 pounds per square inch), while charcoal plate yields with 35 kilogrammes per square millimetre (49,809 pounds per square inch). The first elongates 5—8 per cent. before rupture, the second, 15—20 per cent.

In 1866, and toward the end of 1865, iron rails were made at Terre Noire with a Bessemer steel cover; but this bastard system was abandoned on account of the danger of separation of the weld, to which they were liable after several months of service.

* In this and similar subsequent instances the value of a franc is taken at 18.6 cents.—*Translator.*

About this time the Orleans Company, before deciding in favor of rails made entirely of Bessemer steel, required from Terre Noire two series of tests to prove the uniformity of manufacture. The following are the specifications given for these tests by Mr. Nordling, engineer-in-chief of the Central Railway System of Orleans.*

1st. Two ingots from the same cast to be taken at random, submitted to the tests here given, and the results shown to be practically identical. This same test must be repeated with three different casts.

2d. A standard cast to be made, from which an ingot shall be chosen to which the test just stated is to be applied, six casts to be made in order to arrive at the same standard; an ingot to be taken from each cast, and the same results to be attained by the tests as those attained with the ingot from the standard cast.

These preliminaries settled the tests to be conducted in the following manner:

1st. The ingots, chosen according to the directions just given, are rolled into rails in the usual manner; the pattern of rail adopted is that of the *Paris Mediterranean Railway, with inclined foot for switches.*

2d. Each rail is subjected to a *flexion test,* under the following conditions: The rail placed upon two points of support 1 metre (3.28 feet) apart, is subjected to pressure. The *flexion under the weight* and the *permanent set* after its removal are to be noted.

* Extracted from a manuscript note furnished by the Terre Noire Company, under date of December 15, 1865.

The hydraulic press used in these tests is a very perfect machine, made in the shops of Graffenstaden; the pressure is communicated by three eccentric pumps, so as to insure the utmost regularity.

3d. Pieces of the rails, 2 metres long (6.56 feet), are then tested by shock under the following conditions:

The rail is placed upon two points of support 1.100 metres (3.6 feet) apart from centre to centre; these supports rest directly upon a block of cast iron weighing 10,000 kilogrammes (22,000 pounds), and the ram weighs 300 kilogrammes (660 pounds).

The annexed tables give the results of the tests made as explained above.

By a careful examination of the two tables showing the results obtained, we may draw the following conclusions:

1st. The first series of tests clearly shows the *practical identity* of the two ingots taken at random from the same cast. The regularity of the results up to *twenty-five tons* weight, which represents *nearly the limit of elasticity*, is especially remarkable.

It may even be said that the differences are much less, relatively to the weights sustained, when the elastic limit is exceeded.

2d. This series of tests was not made to show that the casts were identical, notwithstanding which a remarkable regularity is nevertheless shown.

Cast No. 581 is perhaps a little harder than the others, but this is explained, until the weight reaches twenty-five

PRESSURE

Pressure.	
Kilog.,	Lbs.
15,000	33,07
20,000	44,09
25,000	55,10
30,000	66,13
35,000	77,16
40,000	88,18

Limit...

SHOCK TE

Height of	
Metres.	Feet.
1.500	4.92.
1.750	5.74.
2.000	6.56.
2.250	7.38.

PRESSURE T

kilog.,	lbs.,
15,000	33,079. . .
20,000	44,092. . .
25,000	53,107. . .
30,000	66,139. . .
35,000	77,162. . .
40,000	88,185. . .
Limit	

SHOCK TE

Metres.	Feet.
1.500	4.92. . . . .
1.750	5.74. . . . .
2.000	6.56. . . . .
2.250	7.38. . . . .

tons, by some *tenths of a millimetre* difference in permanent set, and has certainly no practical influence.

3d. The second series appears to us likewise to show the *practical identity* of the six casts made with the object of reproducing type No. 564. This type cast is a *little softer* than the three casts of the first series; this was done purposely, and the results correspond within the limits of possibility; the differences in permanent set approach some *tenths of a millimetre*. As in the preceding series, it is only when the limit of elasticity is exceeded that the difference becomes a little greater.

4th. The shock tests show remarkable regularity. The results harmonize perfectly with those of the pressure tests. The deflections under shock shown demonstrate the regularity of the ingots compared with each other, and likewise show small differences of nature. For instance, we observe that cast 581 gives a somewhat *stiffer* metal than 577 and 580. It is equally easy to prove that the second series of casts is generally *much softer* than the first. We think we may draw the conclusion that these experiments have shown the results desired, and, as nearly as possible, solve the questions proposed.

We will add, that the tests were conducted in a perfectly reliable manner. Mr. Delom, engineer of the Central Railway System of Orleans, has made tests to verify those of the engineers of the Terre Noire Company.

The exposition at Imphy contained specimens of Bessemer steel in great variety; the usual manufacture

consists of rails and railway-crossings. I will only add, that lately the pig iron treated is melted in a cupola. It is a step forward, in my opinion, for the nature of the metal is less changed than in a reverberatory furnace.

At the Petin-Gaudet establishment at Assailly, near Rive de Gier, two converters of seven tons each are employed. The product of the establishment in Bessemer steel exceeds five hundred tons per month; and, as a third nine-ton vessel is about to be erected, it will soon be greater. The conduct of the process has attained great regularity. Seven special workmen and fifteen to twenty laborers or common workmen are employed. Gray coke irons smelted at Givors from the ore of St. Léon in Sardinia are chiefly treated. This ore contains:

Protoxyd of Iron	24.00	per cent.
Peroxyd of Iron	62.00	" "
Oxyd of Manganese	0.80	" "
Lime and Magnesia	traces	" "
Quartz	13.00	" "
Sulphur	0.20	" "
Phosphorus	0.00	" "
Total	100.00	

It is perfectly suited for the manufacture of Bessemer metal. Each operation lasts usually from 20—25 minutes; the loss by oxydation does not appear to exceed 12—14 per cent., and the merchantable product averages fully 80 per cent. After the addition of the spiegel pig iron, and before pouring the fined product into the

casting-ladle, they again blow from two to three seconds, according to the nature of the metal desired. The spiegel pig comes from the Petin-Gaudet blast furnaces. Until now both pig metals have been melted in the reverberatory. The Bessemer is likely to replace ordinary cast steel. It is already used for rails, springs, tires, sheet irons, etc. But for some time it has chiefly been employed for many castings, such as housing frames, toothed wheels, pinions, etc., and particularly for cannons of every calibre. According to the special catalogue of the Petin-Gaudet exhibition, the works at Assailly have already furnished above thirty cannons, several of them weighing ten to sixteen tons. I was present at the casting of a similar cannon of fourteen to fifteen tons weight, in October, 1866. Both converters were employed at the same time, or rather by turns at first, on account of the want of power of the blowing-engine; then, previous to casting, the product of both vessels was united in the same ladle. It was thus proved that, when the metal is very hot, it may be kept in repose in the vessel, when turned down, without fear of chilling. A momentary rest in the casting-ladle is indispensable if perfectly sound castings are desired. Bessemer recommends, in fact, in one of his patents, that of February 12th, 1856, that the metal be allowed to *stand* before it is poured into the moulds, to allow the gas to be disengaged from the molten mass. He advises, also, in the same patent, the casting of large pieces by ascension, or *from below*. His advice is followed at Assailly. Can-

nons of steel are cast from a tangential siphon, terminating at the base of the mould, as is done at Ruelle in casting iron cannons. When very hot, cast steel may be kept a longer time in the casting-ladle in a fluid condition than is generally supposed. I have witnessed some casts which lasted ten minutes from the time the vessel was emptied into the ladle until the filling of the last mould. Thus, allowing the molten mass to stand at rest before casting, is to be recommended if we wish to obtain ingots free from blowholes. It is also preferable to cast a single ingot rather than several small ones. Forging pieces of small weight are in that case obtained by dividing the ingot with a chisel, when drawing it under the hammer.

Another means which may be employed to obtain castings without blowholes, consists, according to Bessemer himself, in mixing one per cent. pure pig in the casting-ladle. The manganese and silicon of the pig metal then absorb completely all the oxygen dissolved, and prevent it from reacting upon the carbon. This means has been successfully employed in Sweden and Austria. The difficulty, however, in this case is to obtain perfectly homogeneous products. A later and more efficient device for obviating blowholes consists in causing a powerful pressure to act upon the molten metal during solidification. Cazalat proposed it in his communication to the Academy, January 8th, 1866 (*Comptes rendus*, Vol. LXII., p. 87); and Revollier and Bièrix have employed it at St. Etienne for some months. By employing pressure per-

fectly sound Bessemer steel car wheels are cast in moulds of iron. The pressure attains 500—600 atmospheres.

Bessemer Process in England.

During the last two years the number of Bessemer works in England has greatly increased. The total steel product of every description, in 1861, was barely 1,000 tons per week, whereas last year the total Bessemer steel produced alone was 3,000 tons per week.* The principal establishments employing the Bessemer apparatus are: Sheffield, Brown & Company's works (Atlas Iron Works), and Cammell & Company's works (Cyclops Iron Works); the former contains several ten-ton converters. We may mention the Mersey forges at Liverpool as possessing two five-ton converters; the great establishment of the Northwestern Railway at Crewe, containing four five-ton vessels; the Dowlais and Ebbw Vale, in Wales, having twelve five-ton vessels (six in each forge); in the north of England, Tudhoë, and some others at Manchester, and in the Cumberland hematite region.

When the product is designed for making tires, springs, sheet-metal, etc., gray hematite pig is used almost exclusively, or else charcoal iron from Sweden, Canada, India, etc. White spiegel pig, from Siegen, is always added, to recarburize, toward the close of the operation. When, however, the pig metal is to be fined for rails, the

* The information concerning England is, in part, extracted from two manuscript memoirs by the pupil engineers Ichon and Michel Lévy, written after some travels in 1866.

most ordinary ores are charged in the blast furnace. Thus, at Dowlais, the charge per ton of gray iron for rails is :

TONNES.	LBS.	
1.455	(3,201)	argillo-quartzose hematite, from Cumberland and Lancashire.
0.485	(1,067)	roasted ore from coal-fields selected from the purest and most manganesiferous ores.
1.940	4,268	total.

Hot blast is employed, and the slags are very basic, yellowish-white, stony, and opaque.

The pig iron thus obtained contains :

4.00—4.50 per cent	Carbon.
1.10—1.30 " "	Silicon.
1.50—2.00 " "	Manganese.
Traces	Sulphur.
Less than 0.10 per cent	Phosphorus.

This pig is worked in the Bessemer process with an equal weight of hematite iron, containing a little manganese, very little sulphur, and at most 0.1 per cent. of phosphorus. Both irons are melted together in the reverberatory, with a loss of 6. per cent., and sometimes as much as 10. per cent. Bessemer rail-ends are charged in the vessel before the molten iron is poured in. These rail-ends are charged at the same time with the coke which heats the vessel. The operation itself lasts twenty minutes. The loss is from 12—15 per cent., besides some 6. per cent. due to remelting. To avoid a violent reaction the spiegel pig is only mixed with the fined metal in the casting-ladle. The fined metal is first poured in from the vessel, and then 7.00 per cent. pure pig iron. There is a slight ebullition under the cover of

the scorias, and from this fact alone the mass seems to become homogeneous. The metal is not cast till the lapse of several minutes after the pig iron is added, and when the boiling has ceased. According to the chemist at the Dowlais works the rail ingots should contain :

Carbon	0.15	per cent.
Silicon	0.02	" "
Phosphorus	0.09	" "
Sulphur	0.03	" "
Manganese	0.25	" "

We see that this is *homogeneous* iron and not steel, and. as has long been known, neither phosphorus nor sulphur can be eliminated from iron in the Bessemer converter. The metal becomes brittle and red-short when the proportions of sulphur and phosphorus reach 0.10 per cent. The analysis which I have just quoted proves also that the manganese is not completely oxydized when the blowing is not continued after the addition of the spiegel pig. This is a defect, since manganese tends rather to diminish the tenacity of iron. This practice, however, allows a reduction of from 10. to 7. or 8. per cent. in the quantity of carburizing metal used. Otherwise it is to be feared, however, lest the reaction be insufficient to give a perfectly homogeneous mixture. Bessemer himself appears to believe this, for he has lately invented an iron agitator, consisting of two spiral paddles, protected with refractory clay, which are lowered and turned in the bath in the ladle directly after

the addition of the pig metal. This method appears to me complicated and difficult to apply. If the reaction alone is insufficient to mix the charge, ordinary blowing, such as is still practised in France, is certainly preferable ; in several works in Germany, however, the reaction is also considered sufficient to effect mixture. Let us here observe, that the boiling produced at this moment indirectly proves that the burnt iron at the close of the operation contains considerable oxygen, and not nitrogen alone, for the latter gas would not react upon the pig iron added.

Let us also remember that English hematite irons are not pure enough generally to give really superior steel. Homogeneous iron is rather obtained with little susceptibility of being tempered. In Sweden and Austria, where extra pure pig irons containing manganese are fined, the case is otherwise. Notwithstanding this, the metal resulting from hematite irons is perfectly suitable for tires, springs, parts of machinery, etc., on account of its homogeneity and great tenacity. Ordinary English pig irons cannot be fined for homogeneous metal, because of the sulphur and phosphorus which they contain. In this case, it is necessary to resort to the *double* purification process of Parry, the engineer, which I shall explain at the end of this memoir.

Among English works where Bessemer metal has gained a position, the establishment at Crewe, belonging to the Great Northwestern Railway, deserves especial mention. It is remarkable on account of the new

shingling and hammering machinery with which its skillful manager, Mr. Ramsbottom, has endowed it. Rails and tires of Bessemer metal constitute the principal manufacture. The Great Northwestern Company intends using Bessemer rails exclusively in future, if it is proved that they last ten or twelve times as long as ordinary rails.*

Let us say a few words with regard to the mode of manufacture employed at Crewe. It is known that Bessemer metal has very great tenacity in the ingot. For this reason steel castings are preferred to those of iron. This tenacity is, however, considerably increased by forging hot, which modifies the density, causes the blowholes to disappear, and destroys the crystalline structure. When the form of the piece admits of it, Bessemer metal should be hammered or rolled. Thus steel cannons are forged on a mandrel, cast hollow, or punched with a hammer.

At Crewe, the ingots are prepared in the usual manner, five-ton vessels being used. When the ingots are very large, care is taken to work them immediately while still hot in order to handle the metal economically. By working in this way a short reheating suffices to restore the temperature of the centre to the exterior, while, when cold, an ingot is difficult to heat in the centre without burning the surface. Siemens' furnaces are now frequently used in England for this reheating. The

* At the Crewe Station, the ordinary rails are renewed three times a year, while Bessemer rails have stood three years without change of shape; at Camdentown Station a Bessemer rail outlasted twelve successive iron rails.

rail ingots at Crewe, weighing 230—250 kilogrammes (506—550 lbs.), are reheated upright in a Siemens' reverberatory with a revolving hearth.* The furnace holds twenty; they are charged through a side-door, and taken out at a similar opening in front. The ingots are at least 0.10m. apart (3.9 inches), and the hearth revolves once in two minutes. Rail ingots were originally hammered before passing to the rolls. Now, at Crewe, hammering has been abandoned, by which the work is accelerated, and the rails do not appear to be injured by it. The reheated ingot passes directly to the roughing rolls. The latter differ from the old rolls. They are simply cylindrical sectors instead of complete cylinders, and are fastened by bolts to strong cast or wrought iron arbors, to which the rotary motion is given to and fro, either by racks or connecting-rods, or by the usual reversing. These are Ramsbottom's *Cogging Mills* (toothed or oscillating rollers), shown on Pl. I. and II. (Figs. 1—4), according to the English patent No. 924, April 13th, 1863, and No. 736, March 16th, 1865.† Rolling is thus rapidly done in both directions, which is useful especially when it is required to draw out steel, for which grooves slightly diminishing and a low temperature are necessary. To avoid loss of time, the ingots are carried from one pass to another on a small truck arranged like the *Cabrol Collamineur*. The

* Patent, No. 114, January 13th, 1863.

† Bessemer had already taken out a patent on May 31st, 1856 (No. 1290), for an almost identical arrangement. (For an explanation of the Plates, I refer to the description which closes this memoir.)

finishing rolls do not differ from ordinary trains, and make 80—100 turns per minute. The ingots, after a first heating of from two to two and one-half hours, are put through six or seven passes in the roughing rolls, are reheated half an hour, and then come the nine or ten passes of the finishing rolls. There are altogether sixteen passes, while iron rails require but from nine to twelve passes.

Tire ingots are always worked under the hammer. They are of the form of a frustum of a cone whose height is greater than 0.50m. (19.68 inches). They are hammered on the sides, and in the direction of the axis, so as to reduce the thickness of the disk at least one-half. The centre is then punched and the interior diameter increased to 0.50m. (19.68 inches). To effect this, four heatings are required; the tire is then finished at the end of a vertical roll. (*Buddicom method.*)

Hammering large ingots is done at Crewe by means of Ramsbottom's *duplex* hammer. It is a hammer with two heads but without an anvil. When a large ingot of hard metal is hammered, the shock, or at least the compression, extends but a short distance. The section receiving the blow is elongated, while the centre of the ingot remains intact. The ingot is no longer homogeneous; its mean tenacity is diminished. This defect is lessened by striking the mass simultaneously on two opposite sides. This is the object of the double hammer. It consists of two blocks, provided with friction rollers moving on rails in opposite directions. These two blocks of equal size and the same speed strike simultaneously

upon the ingot placed on a small truck, which is movable in three directions under the guidance of the forger. This simultaneous movement is obtained by a single vertical engine, placed below and geared to the hammers by oblique connecting-rods, or, when the hammers are very heavy, by two horizontal traction engines, or rather direct-acting engines, with single induction valve. In the latter case the hammer-heads are connected directly with the piston-rods like direct-acting hammers; or to the motor cylinders, if the pistons are fixed, which increases the weight of the moving masses. Hammers of this kind have been used two years at Crewe with advantage. They are described in the same patents with the *cogging mills*. For details, the figures and descriptions may be consulted, Pl. V. (Figs. 1—4), which represent the single motor system, and Pl. VI. (Figs. 6 and 7), the double cylinder system.

When the ingots are unusually large, as, for instance, in the case of a horizontal shaft, one metre square (3.28 feet) in section, even double hammers do not prevent unequal elongation. Bessemer uses in such cases a hydraulic forging-press, which has before been used for this purpose at Vienna by Haswell, the engineer, and which was exhibited at London in 1862. A slow but powerful pressure of 1,000 atmospheres acts better upon the interior of the mass than the momentary shock of a hammer. Bessemer has shown that a prism of heated iron or steel, placed upright under a press, enlarges at the centre, while, under a hammer, it is rather enlarged at

the ends. This different action agrees with the results obtained by Tresca in his experiments upon the semi-fluidity of soft bodies. For details of the Haswell and Bessemer presses, the drawings and descriptions on Pl. III. (Fig. 1), and Pl. IV. (Figs. 1—3), may be consulted.

Bessemer Steel in Sweden.

In Sweden, where Bessemer achieved his first successes, the new process is not as widely spread as might be desired, considering the exceptional purity of the raw material. A want of capital, and the fact that the forges are scattered, would seem to be the chief reason for this. The process was first worked at Edsken and Sandviken in the forges of the so-called Högbo Company. Tires and various other forgings were made, using either the Swedish stationary converter or the movable converter. Luyt, in his report on the Swedish Exposition of 1866, mentions a five-ton converter making three blows per day. In 1865 the product at Edsken was 1,200 tons and that at Sandviken 3,000 tons. Both establishments were compelled to stop in 1866 on account of financial difficulties. The iron was charged into the converters directly from the blast furnace. Two other works, Siljanfors and Carlsdal, are mentioned by Luyt as being as yet in the experimental period. The first could only have produced 100 tons of Bessemer metal and the second 55 tons in 1865. The products of the latter were exhibited at the Exposition of 1867, but the works at Fagersta produced the most remarkable

steel. I have already given the proportions of carbon and the elongations of the bars at the moment of rupture. By reviewing these figures and those from Siljanfors, it may be seen that, by working good Swedish irons, real cast steel may be obtained instead of merely homogeneous iron, little susceptible of being tempered. It is to be hoped that the process in question will impart a new impulse to Swedish metallurgy. To accomplish this, however, the stationary apparatus must be abandoned, as it does not admit of proceeding by recarburation, and recourse must be had to the simple mixture in the casting-ladle, which cannot give a strictly homogeneous product. Among the products of the works at Fagersta the scorias from the Bessemer converter were a remarkable feature. They are generally brown, and very much poorer in iron than puddling scorias. Below is given the composition of the scoria from Fagersta as it was given in the notice of the Exposition. It was taken out at the close of the operation.

		Oxygen Contained.
SiO_3	44.30	23.00
Al_2O_3	10.85	5.10
Cao	0.68	10.50
Mgo	0.45	
Mno	24.55	
Feo	19.45	

The excess of silica is from the clay of the vessels, but this circumstance does not explain the poverty of the

scoria in iron, for in such a case it would be still poorer in manganese, since Swedish irons do not contain a large proportion. We may rather conclude that at the high temperature at which fining takes place, owing to the active stirring up of the materials, the oxyd of iron should constantly react upon the other elements of the pig iron, first on the manganese and silicon, and finally on the carbon. The siliceous character of the scoria explains also the reason why phosphorus cannot be eliminated in the Bessemer process, while in puddling and in the low hearth it is removed. That the phosphoric acid may be retained in the bases, the scoria should be basic and not siliceous.*

Bessemer Steel in Austria.

If the Bessemer process is little disseminated in Sweden at the present time, it has, on the contrary, made a rapid advance in Austria, where the spathic ores of the Alps have always been sought for the manufacture of steel. We extract the following details, principally from the *Journal de Léoben*, by Tunner, and from the *Annales des Mines* of Vienna. The first converters were inaugurated at the works at Turrach (Styria) in 1863, and at Heft (Carinthia) in 1864 ; then at the Imperial Works at Neu-

* Caron is wrong in affirming that no means exists by which phosphorus may be removed from pig iron. (*Comptes rendus*, Vol. LVI., p. 828, and Vol. LVII., p. 167.) By remelting the pig iron containing phosphorus in earthen crucibles with manganese or oxyds, the phosphorus will not be successfully removed, because the metallic oxyds present are saturated with silica from the sides, as in the Bessemer converter.

berg in 1864 and 1865, and in the forge at Grätz, the property of the railway company of Southern Austria.

Finally, at this time (1867), works are established at Reschitza in Hungary, and at Wittkowitz in Moravia. The latter establishment is to treat coke irons tapped directly from a blast furnace with a closed front. Tunner finally speaks of the works at Zöptau (Moravia) and at Zeltweg (Styria), where it is also proposed to work the new process. In the works of Styria and Carinthia, the production of Bessemer steel has attained to 3,600 tons.

At Turrach the stationary and movable converters have been tested competitively, but the decision was in favor of the latter, in which the pure pig metal may be added at the close of the operation, thus correcting the defect known under the name of *short* metal. The Swedish converter is, however, simpler and less expensive, and the explosions less violent. For these reasons it has been retained at Heft. Besides, as I have already said, the pig metal for recarburation may be charged in the casting-ladle. Fine products from Turrach were exhibited at the Exposition. The principal manufacture consisted of Nos. 3, 4, and 5 of Tunner's scale. The soft ingots, Nos. 6 and 7, are more cavernous than the others. The same pig iron is used for recarburation as that which is fined.

At the works of Heft, belonging to the Rauscher Company, the spathic ores of the celebrated Hüttenberg deposit are smelted in the blast furnaces. The gray iron made for Bessemer contains 4—5 per cent. of man-

ganese, 1.50—2 per cent. of silicon, traces of sulphur, and 4—4.20 per cent. of carbon, of which 3.5 per cent. is graphite. The first stationary converters were charged with 1,500 kilogrammes (3,300 pounds) as a maximum. At present 3,000—3,500 kilogrammes (6,600—7,700 lbs.) are treated per operation in a converter 1.60 m. (5.25 feet) in interior diameter, and 2.45 m. (8.03 feet) in height. The number of tuyeres is twenty-three, and the diameter of each 0.018 m. (0.7 inches). With two such converters they rely on producing 4,500 tons of ingots annually. The pig metal, tapped directly from the furnace, is charged into the converter by means of a ladle moving upon rails. The length of the operation varies from eighteen to thirty-five minutes, and the pressure of the blast ranges from 0.8—1.2 atmospheres, besides the exterior pressure. Three heats are made in twenty-four hours on an average, although seven heats may be made. The number of special workmen per operation is eight, paid at the rate of 7 francs ($1.30) per ton of ingots produced. Generally, the operation is conducted without the addition of pig iron. The moment for casting the metal, which varies with the hardness of the steel to be made, is chiefly known by the appearance of the flame and sparks which escape from the throat. In the two hundred and sixteen first operations, in 1864, the yield in ingots proper was only 58 per cent.; in 1865 it increased to 72 per cent.; exceeded 81 per cent. in the one thousand and thirty-three operations of 1866, and toward its close even reached 85 per cent. The

mean loss by oxydation, in 1866, did not exceed 13 per cent. The remaining 5—6 per cent. consists of waste, skulls of cast iron or steel,* etc. The principal manufacture is steel containing little carbon, Nos. 5 and 6, for tires, springs, and rails, but never Nos. 1 and 2. I have given the proportions of carbon above on page 25. The ingots are rolled at the forge of Storé, in Lower Styria, with a loss of from three to five per cent. According to the notice of the Exposition, the market price of Bessemer ingots, at the close of 1866, was 290—295 francs ($53.94—$54.87) per ton; that of gray iron for their manufacture was, at the same time, 135—140 francs ($25.11—$26.04).

According to the official statement for the year 1866, it was necessary to renew four earthen tuyeres and twenty-five to thirty refractory bricks for every operation yielding 2.4 *tonnes* (5,280 pounds) of steel ingots. The lining of the Swedish vessel rarely withstands more than ten to twelve charges. Three-fourths of a cubic metre (1.66 cord feet) of charcoal, made from resinous wood, or nearly 100 kilogrammes (220 pounds), are required to heat the vessel per ton of ingots. In conclusion, we see, from the experience acquired at Heft, that a good iron may be directly fined without final recarburation; nevertheless, when the iron is not very pure, it is difficult to obtain, invariably, by this method, a hard steel which is not slightly brittle. It is certainly better, in

* Report of Münichsdorfer, manager of the works, *Journal des Mines*, of Vienna, 1865, and the notice distributed at the Paris Exposition.

such cases, to prolong the fining, and then recarburize the wrought iron by an exactly proportioned quantity of white pig iron containing manganese, charged for that purpose, toward the close of the operation.

At the imperial establishment at Neuberg, in Styria, the Bessemer plant was established under the distinguished direction of Tunner. The two systems were competitively tried, but the Swedish, as at Turrach, was soon abandoned. Since the close of the year 1865 the iron is tapped directly from the blast furnace. The reverberatory furnace or cupola have only been retained for the purpose of testing new irons.

At Neuberg a very great importance is attached to the classification of the seven grades of hardness. Nos. 4—7 are principally made. Plate iron and locomotive springs of metal Nos. 7 and 6, tires of steel No. 5, files and saw blades of steel No. 4, were exhibited at the Exposition. Ingots classed as Nos. 6 and 7 show a bright gray grain and some blowholes in the fractures; the harder ingots, Nos. 5, 4, and 3, show a finer and more compact grain. At Neuberg, as elsewhere, it has been proved that a hot working, resulting from strongly heating the converter and high temperature of the iron, contribute essentially to the success of the operation. The same furnace is tapped for recarburizing. The pig iron is sufficiently pure to require no other. Before casting, however, the mixture is allowed to stand from three to five minutes in the converter when turned down, the gas is disengaged, and the ingots are less cavernous.

To facilitate purifying the pig iron, adding lead and litharge has been tried without marked effect. The same experiments were tried with no better success at Turrach. At both these establishments, as in England, it has been proved that pig irons containing 0.1 per cent. of phosphorus produce at best metal containing little carbon suitable for rails; while, for good steel, irons are necessary which do not contain above 0.04 per cent. of phosphorus.* According to Frésénius the Siegen irons would contain easily as high as 0.06—0.07 per cent. of phosphorus. It is, however, well, to remember that in all cases they contain a higher proportion of manganese as a corrective, and are remelted in a reverberatory before being run into the Bessemer converter, which necessarily eliminates a portion of the phosphorus.

The direction of Neuberg caused a very interesting table of analyses to be printed for the Exposition, which enables us to follow the gradual transformation which pig iron undergoes in the Bessemer converter. The analyses are not, perhaps, strictly exact, but as they agree well with facts observed elsewhere, it appears to me of utility to reproduce them here.

* *Annales de Léoben*, Vol. XV., p. 300.

1°. PIG METAL AND FINED PRODUCTS.

Elements.	Gray Neuberg Pig Iron. (a)	Metal taken after the period of Scorification. (b)	Metal taken toward the close of the Ebullition. (c)	Burnt Iron taken before the addition of the Pig Iron. (d)	Final Product. Mild Steel, No. 6. (e)
Graphite	3.180	"	"	"	"
Combined Carbon	0.750	2.465	0.949	0.087	0.234
Silicon	1.960	0.443	0.112	0.028	0.033
Phosphorus	0.040	0.040	0.045	0.045	0.044
Sulphur	0.018	traces.	traces.	traces.	traces.
Manganese	3.460	1.645	0.429	0.113	0.139
Copper	0.085	0.091	0.095	0.120	0.105
Metallic Iron	90.507	95.316	98.370	99.607	99.445
	100.00	100.00	100.00	100.00	100.00

2°. SLAGS OR CORRESPONDING SILICATES.

Elements.	Slag from the Blast Furnace.	Scoria taken after the period of Scorification.	Scoria taken toward the close of the Ebullition.	Scoria taken before the addition of the Pig Iron.	Scoria taken at the moment of Casting.
Silica	40.95	46.78	51.75	46.75	47.25
Alumina	8.70	4.65	2.98	2.80	3.45
Protoxyd of Iron	0.60	6.78	5.50	16.86	15.43
" Manganese	2.18	37.00	37.90	32.23	31.89
Lime	30.35	2.98	1.76	1.19	1.23
Magnesia	16.32	1.53	0.45	0.52	0.61
Potassa	0.18	perceptible	traces.	traces.	traces.
Soda	0.14	traces.	perceptible	perceptible	perceptible
Sulphur	0.34	0.04	traces.	traces.	traces.
Phosphorus	0.01	0.03	0.02	0.01	0.01
	99.77	99.79	100.36	100.36	99.87

This table proves clearly that copper and phosphorus are not oxydized in the Bessemer process, but when present in very small proportion the sulphur seems to disappear; finally, the manganese, and especially the silicon, are rapidly consumed from the beginning, while

the iron is not *permanently* oxydized until after the silicon, manganese, and carbon have almost entirely disappeared.

We see also, as at Fagersta, that from the high proportion of manganese in the scorias, their poverty in iron does not result from the corrosion of the lining of the vessel, but solely from the powerful action which the oxyd of iron constantly exerts upon the silicon, manganese, and carbon of the pig iron. Besides, we can calculate approximately the proportion of iron actually oxydized, and show that the blast really creates a defect by burning the iron to a considerable extent.

As the manganese of the scoria results only from the pig iron, the weight of the scoria may be estimated according to the proportion of oxyd of manganese contained in it. By comparison of the metals, (a) and (d), it is apparent that the manganese is entirely oxydized up to almost one-thirtieth; also, that in 100 parts of pig metal 3.35 parts of manganese must have passed into the scoria. Now, as the scoria (d) contains 32.23 per cent. of oxyd of manganese, or 18.02 per cent. of metallic manganese, it is evident that 100 kilogrammes (220.5 lbs.) of pig iron should give

$$100 \times \frac{3.35}{18.02} = 18.5 \text{ k. (40.7 lbs.) of scorias (d);}$$

And as, on the other hand, this scoria only contains 16.86 per cent. of protoxyd of iron, or 13.02 per cent. of metallic iron, we see that, in the 18.5 k. of scorias, there are only 2.41 k. of iron (5.30 lbs.); that thus the proportion

of iron *really burned* does not exceed 2.41 per cent. of the weight of the pig iron. The remainder of the loss results from the carbon, silicon, and manganese, whose united weight exceeds 9 per cent., and from the globules of pig metal ejected from the vessel by the blast.

Let us now see what weight of air is required to effect fining. If we admit that the oxydation of the silicon, manganese, and carbon is nearly complete toward the close of the operation, which is nearly the fact according to the results of analysis (d), we will see that there will be per 100 kilogrammes of pig metal—

	Kilogrammes.	(Lbs.)		Kilogrammes.	(Lbs.)	
For	3 93	(8.66)	of Carbon	10.40	(22.88)	Oxygen.
"	1.96	(4.32)	of Silicon	2.12	(4.66)	"
"	3.46	(7.63)	of Manganese	1.00	(2.2)	"
"	2.41	(5.31)	of Iron	0.71	(1.56)	"
			Total	14.23	(31.30)	"

which corresponds to 61.96 k. (136.59lbs.) of dry air.

For a charge of 3.000 kilogrammes (6.600) lbs. then, 1858.8 kilogrammes (4097.94 lbs.) of air will be required; and as an operation at Neuberg lasts at the utmost twenty minutes until the recarburation period, it is apparent that 92.9 kilogrammes (204.80 lbs.) of air, or about 71 cubic metres (2507.48 cubic feet) per minute, are required on an average. Now, at the works at Grätz, where the vessel is under similar conditions as at Neuberg, and is designed for three tons, Castel calculates 75 cubic metres (2648.75 cubic feet) as coming from the blowing cylinders, without any abatement for leakage.* But, as the leakage

* *Annales des Mines*, 6th Series, Vol. VIII., p. 153.

amounts to at least 10 per cent. in the best blowing engines, we see, finally, that the converter does not recieve an excess of air, and that if the iron is not burnt, it is simply owing to a lack of air, and not to the escape of oxygen in the reaction.

I have supposed, it is true, that in the above calculation the carbon is transformed into carbonic acid, whereas a portion probably escapes as carbonic oxyd. But this gas must be partially burned in the vessel by the air which escapes from the metal.

Finally, the conclusion may be readily drawn from the preceding analysis that almost half the silica in the scorias is derived from the pig iron, and that thus the vessel does not seem to be attacked so powerfully as one would be led at first to believe.

The 100 kilogrammes of pig metal have furnished (d) 1.93 k. (4.25 lbs.) of silicon, or 4.02 k. (8.84 lbs.) of silica to the 18.5 k. (40.72 lbs.) of scorias; that; is 22 per cent., whereas the scoria contains 46.15 per cent.

Thus 24.75 against 22 are derived from the vessel.

The Bessemer shop at Grätz has become familiar through Castel's memoir.* The information refers to the Spring of 1865. At first some three to four ton movable vessels were started. The pig iron is remelted in a reverberatory, and comes chiefly from the works at Mariazell. Toward the end of the operation 10 per cent. of spiegel pig is added. I will complete the information furnished by Castel with that published by

* *Annales des Mines*, 6th Series, Vol. VIII., p. 149.

Tunner in 1866, in accordance with the manager's official report for the entire year of 1865.* At first, steel for rails, or rail covers, containing 0.4 per cent. of carbon, was the chief manufacture. Later, tire steel and, even harder steel, No. 3, were also made. The latter, according to an analysis made at Vienna, contains:

Carbon	1.03
Silicon	0.05
Phosphorus	traces
Sulphur	0.05
Manganese	0.07
Copper	0.08
Metallic Iron	98.57
	99.85

The forged, but not tempered steel, broke in testing with a weight of 74.5 k. per square millimetre (105967.6 lbs. per square inch), after an elongation of 3 per cent. only. The very mild steel for boiler plate, from the same works, tested at the Technical Institute at Vienna, broke with a weight of 52 to 58 kilogrammes (73965.7—82501.7 lbs. per square inch), after 14 to 21 per cent. elongation. Other steels tested at the same establishment for the purpose of comparison, gave the following results:

	K.	LBS.
Puddled iron for tires, from Neuberg, broke with a charge of	39.0	(55474.3) per square inch.
Cast steel for boilers, from Petin, Gaudet & Company	53.5	(76101.3) per square inch.
Krupp cast steel for springs	96.5	(137266.3) per square inch.

* *Annales de Léoben*, Vol. XV., p. 312.

According to official information published by Tunner, by authority of the manager, the mean yield in 1863 was :

Ingots	76.70	per cent.
Skulls and waste	8.00	" "
Of which the loss proper	15.30	" "
Total	100.00	

In the last three months, however, the amount reached was 80 per cent. of ingots.

The mean net cost of the ingots equalled 257 francs ($47.80) per ton, in 1865, without counting interest on the capital and royalty for the patent; the pig irons treated were worth from 155—160 francs ($28.83—31.36).

The principal elements of cost are :

		FR.	$.
Pig metal		210.35	(39.12)
Fuel— Lignite at 25fr. ($4.65) per ton,	For blowing engine	6.00	(1.12)
	Heating the vessels	12.00	(2.23)
	Melting in reverberatory	36.80	(6.84)
Labor and managing		19.75	(3.67)
(There are twenty special laborers paid at the rate of 60 francs ($11.16) per day, without counting mechanics.)			
Materials of various kinds		26.70	(4.97)
Total		fr.311.60	($57.95)
Deducting for skulls and waste utilized		53.80	(10.00)
Net cost*		fr.257.80	($47.95)

This net cost exceeds that of the pig iron by 100 francs ($18.60). This increase in cost, however, would be 70 francs ($13.02) at most, if the pig iron were tapped directly from the blast furnace. This approaches the

* At the works of Grätz, this is also the net cost of iron rails with Bessemer steel covers.

cost which I mentioned, in accordance with Bessemer, at Woolwich, in my first memoir of 1861 (*Annales des Mines*, 5th Series, Vol. XVII., p. 533). It is evident, however, that at present more favorable conditions exist in a large number of localities.

Bessemer Process in Belgium and Germany.

The Belgian Bessemer works are situated at Seraing and Ougrée. Some of the products were exhibited at the Exposition, but information concerning the nature of the raw material used, and the condition of the industry, is wanting. In Prussia, the Bessemer process is employed at Hoerde, Bochum, and Essen, at Krupp's establishment. The irons worked there are from Siegen and the Duchy of Nassau. The works at Hoerde have exhibited rails, tires, and axles of Bessemer steel. Some solid mounted wheels were exhibited there, having Bessemer steel tires fastened upon an iron plate, by welding or by shrinking.

The application of Bessemer steel at Bochum is at present confined to rails. At these works the product is not considered sufficiently uniform for the manufacture of reliable axles.

The experience of the Austrian establishments should be a full reassurance in that respect. Krupp has not exhibited anything under the denomination of Bessemer steel. The printed statement sets forth that all the products were cast from crucibles. It is, however, known, notwithstand-

ing the mystery which surrounds Krupp's works, that there are several Bessemer converters at Essen. Whether they are worked or not, and under what conditions, I do not know. In any case, it appears certain that superior steels are here, as elsewhere, made in crucibles, and that even Bessemer steel is often thus remelted.

An experimental converter has just been established in the royal works of Königshütte, in Silesia. The experiments now being undertaken cannot fail to afford useful information upon some points in the new method of fining, which are as yet obscure.

In Saxony, two three-ton vessels are in active operation, at Marienhütte, near Zwickau. The coke iron from the same establishment is worked, which is smelted from the red and brown hematites of the country. The products appear quite good.

Bessemer Process in Russia.

The Bessemer process has been established in Russia, at one of the works belonging to Prince Demidoff, at Nischné Taguilsk, since the commencement of 1865.* The movable vessel is employed, but the numerous small vertical tuyeres have been replaced by two single lateral tuyeres, arranged similarly to those of the Swedish stationary vessel. The tuyeres are 0.04 m. (1.57 inches) in diameter, and have a slight inclination. They make, as in Sweden, a certain angle with the horizontal, so as to

* *Journal des Mines d'Autriche*, 1865, p. 406 (Tunner's Memoir).

produce a gyratory motion, which prolongs the passage of the blast through the pig metal. The tuyeres withstand twelve heats. They are lined with sheet iron, which allows of their being cleaned without abrasion. This is a positive advantage, since the ordinary tuyeres in the English converters last a much shorter time. In this system of large tuyeres Tunner recognizes a possibility of taking an assay, by means of a polished rod, as in fining crude copper.* The usual charge at Taguilsk is from 1,750—1,800 k. (3,858—3,968 lbs.), and, according to information furnished by the manager of the works, most satisfactory results are obtained.

* The method of taking an assay proposed by Tunner has been lately practised in several German establishments. M. Douvillé, a student engineer of mines, saw it employed last summer (1867) at Grätz, Neuberg, and Zwickau. When it is desired to take an assay, the ordinary vessel is turned down as for the reception of the recarburizer, and the blast stopped. By means of a polished rod or paddle larger than usual, a thimble or thin plate of scoria is taken out by attachment, which immediately congeals. Its appearance resembles that of enamel. As long as the metal has not reached the state of burned iron, the enamel is a light chestnut brown on the upper surface, and a pale, almost white, olive tint in its fracture. As the operation advances and the reducing action of the carbon of the pig iron is less energetic, both tints become darker. When the iron is burnt the enamel is almost black on the surface, and turns to a bright green in its fracture. It is then time to tap the recarburizer and add more or less of it, according to the number of hardness desired. Or, if it is desired to maintain the proportion of pig metal added invariable, it is tapped more or less soon, the more or less dark shades which I have just mentioned being the guide. The first method is surer and gives more certain products. I have recommended the use of this mode of assay in France. Below is given the proportion of silica in two scorias, taken at the extremes of an operation, and brought from Germany by Douvillé. The light brown scoria contained 53 per cent. of silica, and the dark scoria 49 per cent. These results accord with the analysis from Neuberg, quoted above. The dark shade corresponds to scoria (*d*), and the results show the latter to contain three times as much iron as scorias (*b*) and (*c*).

Bessemer Process in Italy.

In Italy the first trials were undertaken on a small scale, in 1860, by Ponsard, at that time manager at Folonica, and afterwards, in 1862, at Sheffield, before a commission of Italian engineers.* M. De Cizancourt published the report of the said commission,† in the *Annales des Mines*. I will not recur to it, but would add that, in accordance with these experiments, a Bessemer works has been established by Ponsard at Piombino. Some of the products obtained figured at the Exposition.

Bessemer Process in America.

Finally, let us mention that the Bessemer process has gained a foothold in the United States of America. The excellent Lake Superior ores yield pig irons especially adapted for steel.

In résumé, such is the actual condition of steel manufacture by the Bessemer process. Let us now see wherein it is lacking.

Defects of the Bessemer Process.—Means of Remedying Them.

The defect in this manner of fining, is, that it is not applicable to pig irons containing sulphur and phospho-

* *Industria del ferreo in Italia*, p. 386. Torino, 1846.
† *Annales des Mines*, 6th Series, Vol. IV., p. 231.

rus. The operation is too rapid, the temperature too high, and the scorias too siliceous to permit the sulphur and phosphorus to be eliminated. What is to be done to remove these substances?

Professor Wedding, in his memoir,* proposes to force out the scorias, by the action of blast, before the end of the decarburizing reaction. But the scorias could never be completely removed; and, if they contain an excess of silica, phosphoric acid could not remain in them. It would be better to remove phosphorus, by a kind of refining, separately in a reverberatory or low hearth. Only, as the silicon is oxydized at the same time, the first period of Bessemer fining would be shortened. Accordingly, the temperature of the metal will be lower. Obstructions or explosions would result therefrom. To secure a hotter working, it would be necessary to fine the pig iron at a very high temperature, in a Siemens' furnace, adding lime and oxyd of manganese, and then to charge the fined metal directly from this furnace into the Bessemer converter. Or, better, a certain quantity of pig iron, free from phosphorus, could be previously treated in the Bessemer converting vessel, and the fined metal containing phosphorus added just before the commencement of the reaction period. Nevertheless, complete purification could not be thus effected. The metal produced will be of ordinary quality, and in all cases homogeneous iron, rather than steel proper, would be ob-

* *Journal des Mines de Prusse*, Vol. II., and *Journal des Mines d'Autriche*, Vol. XV.

tained. But with the same proportions of phosphorus and carbon the cast wrought iron, on account of its homogeneity alone, will possess greater tenacity than ordinary puddled iron welded and hammered. It is to be hoped that fining ordinary pig irons by means of fusion will one day be successful. At all events, this may be arrived at by the Parry process, which I have already mentioned, and to which I shall soon recur.

Several have hoped to remove sulphur and phosphorus by means of hydrogen. Sulphuretted and phosphoretted hydrogen have little stability at ordinary temperatures, and, *a priori*, their formation does not appear possible when iron is present. But at high temperatures reactions are often very different, and two volatile substances will rather remain combined at a white-red heat, than a volatile and a stable element, such as phosphorus on the one hand and iron on the other. Thus, it is known that steam separates sulphuretted hydrogen in passing over red-hot iron pyrites. The reaction takes place even when the sulphur is combined with the iron in very small proportion. Boussingault has proved that by causing steam to pass over molten steel, sulphuretted hydrogen and some little ammonia are evolved, and Bouis has observed the same reaction in using hydrogen alone.*

On the other hand, Minary assures us that phosphoretted hydrogen is disengaged when forge cinder, containing a sensible amount of phosphorus, is mixed with small coal and calcined.

* *Comptes rendus*, Vol. LII., pp. 1,008 and 1,009.

It is this double reaction which Cazalat has sought to apply by causing superheated steam to pass through pig iron in a state of fusion in a reverberatory; unfortunately the chilling effect of the steam is such that it is impossible under the circumstances to maintain the metal in a molten state.

Bessemer, in his numerous experiments in fining, likewise made trial of the action of different gases upon fused pig iron. His first patent* already mentions injecting air and steam mingled together or taken separately. He operated in a crucible placed in a furnace with blast, and conducted the air and steam into the furnace by means of a tube of refractory clay. Gilbert Martien, of Newark (America), even preceded him in this method. As early as September 15th, 1855, Martien had applied in England for a patent for *purifying* pig iron in a fluid state by the aid of blast or steam. In his second patent, No. 2,768, applied for December 7th, 1855, Bessemer proposes to employ *hot* blast and to use steam only, *at first*, to expel *sulphur*. He had distinctly proved, since applying for his first patent, that steam chills the iron, while air raises its temperature. He also proposes to inject substances containing carbon, and for the rest, recognizes in his patent that the action of air and steam upon pig iron in the puddling furnace had been already tried.

On the 15th of March, 1856, Bessemer mentions, in a third patent, No. 630, oxyd of iron as an oxydizing agent and carburetted hydrogen as a reducing agent. He in-

* English Patent, No. 2,321, claimed October 17th, 1855.

jects the latter *toward the close* to remove the little oxygen which remains united with the iron. He had proved that iron becomes *short* by the action of too prolonged blast.

In his patent of August 19th, 1856, No. 1,938, Bessemer attempted to diminish the waste by a current of carbonic oxyd,* and to expel *sulphur* and *phosphorus* by injecting gases combined with *hydrogen.* It is apparent that Bessemer had the *purification* of ordinary pig irons especially in view from the outset, but he recognized the practical difficulties, or the inefficiency of the reagents, since it is known that he himself appreciated the impossibility of fining pig irons containing phosphorus and sulphur by his process, and, in fact, his two patents defining it (No. 578, of March 1st, 1860, and No. 56, of January 8th, 1862) speak only of injecting *air.*

At all events, even by the use of gas previously formed, and not steam, the principal difficulty will always be to maintain the iron, and still more the half decarburized metal, in a state of fusion for any length of time. While air, even when employed cold, raises the temperature of the iron, gases containing hydrogen, and especially steam, even when superheated, will always produce the opposite effect.

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* Cizancourt also proposes the injection of carbonic oxyd toward the close of Bessemer fining. *Annales des Mines*, Vol. IV., p. 294.

Bérard's Process.

Bérard has attempted to surmount the greater of the two difficulties of which I have just spoken. He makes use of a double reverberatory furnace heated by gas; in this furnace the pig iron is worked alternately with air and heated hydro-carbon gases. The blast oxydizes and heats, while the hydrogen is to remove the sulphur and phosphorus. The first experiments were made two or three years ago, at Decazeville; the plant was then established on a larger scale last winter at Montataire. The apparatus is composed of two reverberatory furnaces joined together, each heated with gas from a generator. The hot air and gas enter in the usual manner through a double battery of blowpipe tuyeres (Plate VI., Figs. 1 and 2). A compartment filled with incandescent coke is placed between the two furnaces, of equal size with them, and separated from each by a small open brick wall. The hearth is formed of a box of heavy sheet iron supported upon an iron wagon, like the English cupels, for fining argentiferous lead. The interior of the box is lined with argillo-carbonaceous brasque rammed solid.

The gas intended to heat the double furnace enters alternately through either battery. If it is supplied by the battery on the right, the products of combustion enter from the left, and thence to the chimney, passing through the compartment filled with incandescent coke. There the carbonic acid becomes carbonic oxyd, so that the gaseous atmosphere of the furnace on the left will be

more reducing, and not so hot as that of the furnace on the right. When the difference in temperature of the two furnaces becomes too great, the direction of the gaseous current is changed, so that each furnace receives in turn a current of hot gases in a state of combustion, and gases rendered reducing. Both hearths are charged with pig iron. At Montataire the charge is 600 kilogrammes (1,320 lbs.) for a basin 1 metre (3.28 feet) on a side, so that the depth of the pig metal bath is 0.10m. (3.9 inches). Two tuyeres, inclined 45 degrees, dip into each bath, being arranged like those of the English fineries, except that they are both placed on the same side of the furnace. They are made of refractory clay, and may be advanced or withdrawn separately, by means of a rack. They are each composed of several parallel nozzles uniting with one another. Thus, in turn, hot blast is driven through one tuyere, and hydrogenous gas through the other. The latter is prepared in a kind of cupola furnace charged with coal, and blown by a mixture of air and steam. The gases produced are really composed, then, of nitrogen, carbonic oxyd, and hydrogen more or less carburized. They are conducted into a gasometer, whence a special blowing machine forces them through the heating apparatus into the bath of pig iron.

The gases of the generator are further desulphurized by lime, like the gas used in cities. Finally, the furnace in which combustion takes place receives the inclined air current at the same time that the other, whose atmo-

sphere is reducing, receives the hydrogenous gas through the nozzles. Thus two charges are fined simultaneously, or, rather, they are alternately exposed to the action of air and reducing gases, so that if the latter really removes sulphur and phosphorus, it would be possible by this process to fine pig irons of less purity than those treated in the Bessemer.

Unfortunately, the experiment has not been as yet really successful. The two blowing engines at Montataire are not sufficiently powerful to inject the air and hydrocarbon gases at the same time. Up to the present time ordinary fining by means of air, allowing one bath to stand alternately some minutes at rest, is all that has been accomplished.

The operation thus conducted differs then but little from the practical working of the Bessemer vessel, and in the main nearly identical products are obtained.

The casting is effected by piercing as usual the wall opposite the tuyeres, and the steel is received in a distributing ladle similar to that of the Bessemer establishments. The fining proper lasts on an average nearly half an hour.

What the future of the Bérard process is to be, cannot be predicted. The question of purification by means of gases containing hydrogen, remains unaltered. The perseverance of the inventor is deserving of praise, and in the interest of all success is to be desired. It would be a considerable step in advance to obtain cast steel or homogeneous iron with ordinary ores, since pure ores are relatively of rare occurrence. To be successful, however,

the plant must be simplified. The utility of the double furnace is not apparent to me, nor is that of employing a reducing atmosphere during the injection of hydrocarbon gas. The reducing atmosphere acts upon the scorias, and causes the oxyds of the foreign substances, which we seek to eliminate, to recombine with the metal. A simple furnace, heated as required with a Siemens regenerator, would seem to me preferable. The air for oxydation and gas for purification could be injected in turn, but, on account of its chilling effect, the injection of the gas should last relatively but a short time. The carbonic oxyd and hydrocarbons would effect a partial recarburation of the iron, while the hydrogen would remove the phosphorus and sulphur. It remains to be learned, as I stated in the beginning, whether this last reaction really takes place.

Fining by Reaction.

The manufacture of steel by *reaction* has been long understood.

Réaumur, in his remarkable treatise, "The Art of Converting Iron into Steel," published in 1722, says, on page 250: "Iron is transformed into steel by immersing it for a short time in melted cast iron." And adds: "This process of steel manufacture is in use in some countries, and has already been described by Vanaccio in his *Pyrotechnie*, Book I., Chap. 7." Réaumur says in addition, on page 256, that steel may also be obtained "by fusing iron scrap in cast iron," and that he has obtained *forge*

steel by thus mixing with cast iron sometimes one-fourth, sometimes one-third of wrought iron.

Instead of wrought iron, *oxyd of iron* may be used, and the fundamental idea of this method is already shown in Réaumur's treatise when he states (p. 472) that cast iron is rendered soft by *crocus martis.*

Chalut and Clouet have since undertaken similar experiments. In 1798 the latter states positively that iron or cast steel is obtained by remelting pig metal with oxyd of iron ;* by taking one-fourth oxyd of iron, wrought iron is produced ; by using less than one-fourth, steel results. Mushet has since taken a patent for the same mode of manufacture.† Finally Captain Uchatius causes wrought iron and oxyd of iron to react together upon pig iron. This latter process is made the subject of an official report by Messrs. Combes, Levallois, and Thirria,‡ and was more completely described by Hartmann in his "Progress of Metallurgy."§

Below are given the mixtures employed according to Hartmann :

	For hard Steel.		For Medium Steel.		For mild Steel or homogeneous Iron.	
	Kilog.	Lbs.	Kilog.	Lbs.	Kilog.	Lbs.
Granulated Pig Iron.....	1000	2200	1000	2200	1000	2200
Spathic Iron or Oxyd of Iron...	250	550	250	550	250	550
Peroxyd of Manganese.....	15	33	15	33	15	33
Wrought Iron			125	275	200	440

The fusion is effected in crucibles as in ordinary steel manufactories.

* *Journal des Mines*, Vol. IX., p. 8.

† Hassenfratz, Vol. IV., p. 91, and Vol. IX., *Philos. Magaz.*

‡ *Annales des Mines*, Vol. VIII., 473.

§ *Progrès de la Métallurgie*, Vol. I. (year 1858.)

By the use of oxyd of iron a veritable fining results, while by mixing wrought and cast iron, a simple separation of carbon and foreign substances is effected; consequently the purity of the product in the latter case depends entirely upon that of the metals themselves. Even then, however, there is a fining and partial oxydation. According to the experiments by H. St. Claire Deville, the gases of the hearth penetrate the crucibles and act as oxydizing agents. In practice we really approach by other means the processes of Clouet and Uchatius, by adding a certain portion of oxyd of manganese to the mixture of the two metals. This process of manufacture is much more extensively used than is generally supposed. For a number of years most large manufacturers of cast steel have obtained common steel by this method of reaction. Krupp in Germany, Vickers and Naylor at Sheffield, and several manufacturers on the Loire, have constantly employed it during twenty or thirty years. I would merely refer here to the Trinquet steel, which has been made since 1846 by this method at St. Étienne (p. 219). Cemented steel is melted only to obtain a steel of superior quality.

The manufacture of cast steel was systematically investigated about the year 1860 by Alexandre, an officer of artillery.* He experimented in large crucibles succes-

* Patent of November 29, 1860, and manuscript report. In most experiments a small proportion of carbonate of ammonia was added as a purifier. It is harmless, very probably because of its volatility, at least inasmuch as the ammonia performs no real part of a useful nature except by the hydrogen it contains.

sively with mixtures of cast and wrought iron, cast iron and filings (or turnings) of cast iron partially oxydized by prolonged exposure to air, and finally with turnings and filings in the natural state, together with those which were oxydized. The turnings and filings were obtained almost exclusively from the shops of the Imperial Navy.

1st. *Cast iron and iron.*—Mixtures were made successively of 3 of iron to 0.1, 0.2, etc., as high as 2 of cast iron.

With as much as 0.4 of cast iron, homogeneous iron and mild steels are obtained.

After the addition of 0.3 of cast iron, the metal casts without blowholes and becomes moderately hard, then hard.

As much as 3 of iron for 1 of cast iron may be used without inconvenience, working in closed crucibles. The quality of the product depends, of course, upon the purity of the materials employed.

Experiments were made with charcoal iron from Ruelle and soft Glasgow pig metal. As might be foreseen, the latter was little adapted to such use. The steel was short.

2d. *Pieces of cast iron and oxydized filings.*—By mixing 3 of oxydized filings with 0.5—1 of cast iron, a soft steel is obtained; 2 of cast iron giving hard steel, and 3 of cast iron extra hard steel difficult to forge. There is a loss of from 8—10%, owing to rust, and a vitreous scoria is produced which covers the bath.

3d. *Filings of cast iron and oxydized filings.*—When the

pieces of cast iron are replaced by fresh filings, as might be expected, the product becomes softer.

The steel remains *soft* as long as the proportion of fresh filings is 2, while that of oxydized filings is 3.

When 3—4 of ordinary filings are taken with 3 of oxydized filings, *hard* steel is the result. Beyond this the tenacity decreases, and when 6 of crude filings is reached the cast steel becomes slightly short. Finally with 9 or 10 of unoxydized filings, a sort of refined pig metal or raw steel is produced, which is still, however, somewhat forgeable. The loss and scorias amount to 10%—12%.

The steels obtained from oxydized filings have more body than those obtained by a simple mixture of cast and wrought iron. This proves the utility of oxyd of iron when we work with vessels completely closed. Thus, to oxydize foreign elements, in the absence of air, we may have recourse to the oxyds of iron and manganese.

The majority of the facts I have just stated had been already proved, according to Réaumur and Clouet, by Mushet, Hassenfratz, Bréant, William Vickers, and others. I am, also, about to enter into some new details, to render the history of these processes complete, and show how the reverberatory has of late become a substitute for crucibles.

According to Vandenbroeck, inspector of the School of Mines of Sarre, Hassenfratz describes two furnaces which were used in England as early as 1812, for manufacturing cast steel by reaction.*

* Hassenfratz, *Siderotechnie*, Vol. IV., p. 93—95 (year 1812).

The first is a galley furnace for four crucibles, heated by coal. In it the mixture of cast iron, scraps, clippings, hammer scales, etc., is melted. The second is an ordinary reverberatory, charged with the same mixture. I quote the text to preclude the possibility of doubt regarding the method of manufacture pursued in England since that time, if not continuously, at least by way of experiment.

§ 1124. "The mixture designed to produce the steel is melted in ordinary reverberatory furnaces, in the lower part of which a kind of crucible is contrived. The metal placed on the bridge is heated, melts and flows into the crucible, where it accumulates. The cast iron becomes covered with scorias, not only those contained in the iron, but also those formed by the partial fusion of the earthy glass which flows from the hearth. If the scorias are in sufficient quantity the bath is left at rest as long as the surface appears to bubble, and carbonic oxyd is discharged in the form of a violet flame. When ebullition ceases a piece of green wood is introduced into the bath, and the liquid metal is stirred below the scoria, in order to facilitate the separation of those scorias which remain in the cast iron and adhere to the metal.

"At the moment the fining of the pig iron commences, the principal workman introduces a small spoon into the bath, to remove a little of the cast iron from below the scorias. He pours it into a test-ingot mould and tries it at the forge. He continues to take assays until what is removed can be forged. Then he examines the grain of

his steel; if it is too soft, the workman throws bars of over-cemented steel into the bath, to supply carbon without changing the mode of fining; if it is too hard, he throws into it clippings of wrought iron, and sometimes even old iron, to dilute the carbon by increased volume, or to burn it partially; then he removes the scorias and pours into the mould the cast steel, which is immediately forged into a commercial product."

From the preceding, it appears that the direct manufacture of cast steel has been known, *in principle* at least, since 1812. The process, however, did not seem to be extensively adopted, either in England or elsewhere. The difficulty of producing the desired temperature with regularity, and especially, I presume, the inferior quality of the steel produced, owing to the ordinary quality of the cast irons used, caused the method to be abandoned, and, in a measure, even forgotten completely.

Later, however, in 1824, we observe Bréant return to the same idea.* After having proved by the crucible that "100 parts of the filings of very gray pig iron and 100 parts of the filings of similar iron, previously oxydized, produced a beautifully damasked steel," he adds, "The blackest pig irons are the most successful. I am convinced that with such pig irons cast steel could be produced in a large way, in reverberatory furnaces, by pursuing a process analogous to that employed in purifying bell metal, that is to say, by adding to the fused

* *Annales des Mines*, 1824, Vol. IX., p. 326.

metal a portion of the same metal oxydized, or, better still, natural oxyd of iron."

After this, and for twenty years, the reverberatory furnace seems forgotten. It is mentioned anew, in 1845, and in terms but little differing from those employed by Hassenfratz. On the 4th of August, 1845, Josiah Marshall Heath makes a claim, in England, for a patent, No. 10,798, for the manufacture of cast steel by reaction in a reverberatory heated with carbonic oxyd gas.*

The pig iron is tapped from the blast furnace directly, or, better, it is remelted in a reverberatory or a cupola. It is conducted into a basin covered by an arch, and strongly heated by an ordinary battery of double gas and hot blast tuyeres. The gas is obtained from a blast furnace or a special generator. The relative proportion of wrought and pig iron varies with the nature of the pig iron and the hardness of steel desired. For ordinary steel, however, Heath directs equal quantities of iron and wrought iron to be used. The latter is taken in the form of clippings, ends of bars, or in the state of *sponges* obtained from rich ores reduced in a cementation furnace with charcoal. Before mixing the iron with the cast iron it is recommended to heat it to a white-red in a special reverberatory, or on a hearth supplied with waste heat, placed between the steel furnace and the chimney. As soon as the heated iron is thrown into the pig iron bath, the mixture is stirred and assays taken. The stir-

* Heath took out a first patent, April 5th, 1839, for the manufacture of steel by reaction in crucibles, or in a cupola.

ring is occasionally renewed, either by using an iron bar or a wooden pole. The metallic bath is protected from the air by a vitreous flux.

The patent gives as a specimen furnace a circular reverberatory, having a hearth for waste heat and a cupola near at hand, for melting the cast iron. There is a drawing of the furnace according to the English patent, on Plate VI., Figs. 3—5.

Looking at the process in review, it appears to resemble in every particular that described by Hassenfratz, and the same causes prevented it from succeeding. At that time only superior steels were sought, whereas the ordinary English pig irons could as well be treated.

Thereupon a fresh pause of ten years ensued; then, February 16th, 1854, John Davie Stirling claimed patent No. 375 in England, for the manufacture of steel by reaction in crucibles or in a reverberatory.

He proposes to cause the powdered oxyd of iron to react upon pig iron.

In the following year the indefatigable Bessemer devoted his attention to the same subject. He took out a patent (No. 66) on January 10th, 1855, "for the fusion of steel in a reverberatory containing a basin, in which are placed molten vitreous substances, whose object is to form a covering for the steel, and protect it from the action of the atmosphere and that of the furnace gases."

A similar patent was claimed October 25th, 1858, by Sudre, in France. He undertook his first experiments

in the shops of the Northern Railway, and in December of the same year Lan assumed direction of similar experiments in the works of Petin, Gaudet & Co., at Rive de Gier.*

From November, 1860, to March, 1861, Sudre devoted himself, at the forge of Montataire, to a second series of experiments, undertaken at the imperial expense. They were described in an official report signed by Colonel Treuille de Beaulieu, H. St. Claire Deville, and Captain Caron†. These first experiments were only partially successful.

The required temperature was attained, it is true, but neither the furnace at Montataire, nor that at Rive de Gier could withstand more than a few operations. Instead of brick, the hearth should have been made of refractory concrete rammed solid. This was done by Alexandre, manager of the imperial establishment at Villeneuve, near Brest. Subsequent to the fusion in crucibles which I have described, this officer was authorized to erect at Villeneuve the first reverberatory furnace for 300 kilogrammes (660 pounds), in December, 1860, and a larger furnace for 1,200 kilogrammes (2,640 pounds), in the following year, at the foundry of Ruelle. The general disposition of the reverberatory resembles that of the second fusion furnaces in gun foundries. The hearth, however, consisted of a single piece of rammed refractory concrete, 0.06 m. (2.4 inches) in thickness, com-

* *Bulletin de l'Industrie Minérale*, Vol. IV., p. 576.
† *Annales des Mines*, 6th Series, Vol. I., p. 221.

posed of equal parts graphite and refractory sand. The fusion was successful, and the furnace withstood twenty or thirty operations without extensive repairs. Some projectiles and several cannons were cast. The products, unfortunately, were of inferior quality. Let us finally add that these defects, little tenacity, lack of body, shortness, result, not from the method of fusion, but from the nature of the materials themselves. Cast steel has been made, either by simply melting old files, rendered more or less dull by use upon various metals, or by applying the three methods of reaction previously tried in crucibles, viz.: cast iron and iron, cast iron and oxydized filings, crude filings and oxydized filings, all beneath a covering of glass or blast furnace slags. The pig iron, as I have said, was chiefly obtained from Glasgow. As is well known, it is a black pig iron for second fusion, smelted with hot blast and raw coal, the last which should be selected. The scrap iron also, and the filings, were from various sources.

In these experiments the fact that good steel will never be obtained with other than pure materials, has been too much disregarded.

In the course of the operation two modes of assay were adopted; the metal was removed by means of a spoon, and a little bar, measuring 0.01 m. (0.39 inches) on a side, was cast in an ingot-mould; or, better, a sort of thimble was removed on the end of the polished iron rod, by attachment, as is done in working copper (*Spiess Probe* of the Germans).

It was observed that to obtain a steel free from blow-holes, a very hot bath was required, in which case nothing became attached to the polished rod. It was also proved that the steel lost its tenacity, if kept too long in a state of fusion beneath the slags. Clouet had already made this observation in his crucible experiments, and steel founders are well acquainted with it. The steel is charged with silicon, and probably, also, with the earthy metals. This may be remedied by adding oxyd of manganese.

For given proportions of iron and cast iron, or oxydized filings and cast iron, the steel produced was of the same nature, and possessed the same degree of hardness as that made in crucibles ; the loss, also, was the same. Thus, the covering of scoria protects the metal completely, and, according to this, it is evident that the reverberatory is as well adapted to the fusion of steel as the crucible. The necessary temperature may be readily obtained, especially by resorting to a heated blast, as is done at the works of Petin and Gaudet, where the steel is melted with coal regularly, in reverberatory furnaces, with crucibles. The process, however, which merits the preference, whether in regard to economy or facility in working, is the Siemens furnace used by Martin.

At Villeneuve, 400 kilogrammes (880 pounds) of coal were consumed in the reverberatory per 100 kilogrammes (220 pounds) of steel, when charged cold, and 275 kilogrammes (605 pounds) in the succeeding operations, when charged hot. In the first instance, the operation

lasts from four to four and one-half hours; in the second, from two hours and one-half to two hours and three-quarters. In the regular working, three operations were made in twelve hours.

The Martin Process at Sireuil.

The experiments made at Villeneuve were discontinued in the latter part of the year 1862, owing to the unsatisfactory quality of the products. They were arrested midway. The administration of the imperial navy did not possess the perseverance displayed by Bessemer.* The latter failed, at first, as did Alexandre, by reason of the quality of the pig irons used, but resumed his experiments with good Swedish pig irons, and succeeded. Martin had a similar experience in the treatment in the reverberatory furnace, at his establishment at Sireuil. After numerous trials, a first patent was secured, July 28th, 1865; an additional certificate on December 19th, 1865, and ten similar certificates of minor importance, during the course of the years 1866 and 1867.†

The method consists in producing cast steel in a reverberatory furnace, by means of the reaction of wrought

* In February, 1867, I was consulted by his Excellency, the Minister of the Navy, regarding M. Alexandre's experiments. I demonstrated the causes of the bad quality of steels, in my report, and advised a better selection of raw material. I advised puddled or cemented steel of good quality, for simple fusion, and a mixture of cast iron of a steely nature, and superior wrought iron, or pure oxyds, for the reaction process. I added, that success did not seem doubtful to me, particularly by the aid of the Siemens furnace, which allows the flame to be made oxydizing or reducing at will.

† Mr. Martin has just published a list of them in a pamphlet, called "A New Process for the Manufacture of Steel and Homogeneous Metal."

upon cast iron, with or without the addition of rich ores of iron.

The furnace is a reverberatory with a single door, and has Siemens regenerators attached.

The only door is at the middle of one of the long sides, while on the opposite side, at the lowest part of the hearth, there is an opening with a canal for casting. The gas of the Siemens apparatus enters and passes off at the ends of the furnace. The interior section is a truncated oval, or a rectangle, with contracted ends. The hearth is of refractory argillo-quartzose sand. It has a thickness of less than 0.10 m. (3.9 inches), to enable it to withstand the elevated temperature of the furnace. A strong iron plate, cooled below by an air-current, or by vapor and air, supports the sand bottom. The hearth is repaired after each operation, by ramming fresh sand into the holes which have been produced. With these repairs it lasts a considerable time. The side walls are retouched, of course, every week, and the arch entirely repaired every three weeks, or usually at the end of 25—30 operations. On the casting side of the furnace an iron tramway, with wagons, or a revolving platform, brings the series of ingot moulds successively under the flowing metal, till the casting is finished. Near the melting furnace is placed an ordinary flat-hearth reverberatory furnace, in which the cast iron pigs and packages of wrought iron, added during the operation, are heated to a white red. The dimensions of the furnace depend, of course, upon the quantity charged. At Si-

reuil, the charge is 1,500—2,000 kilogrammes (3,300—4,400 pounds); at Verdié's works, at Firminy, from 3,000—3,500 kilogrammes (6,600—6,700 pounds). As in the Alexandre furnace and Bérard's apparatus, the bath should be 0.10 m. (3.9 inches) deep, or nearly so.

The operation is very simple. As I have already stated, steel may be made either by the simple reaction of wrought upon cast iron, or by the oxydizing action of rich iron ores. Owing, however, to the difficulties arising from the difference in specific gravity of iron and ore, and because of the corrosive action of the latter upon the furnace, it is harder to obtain good results by the latter means.

Mr. Martin gives the preference to the method of reaction by means of wrought iron, which is evidently much less complex. The experiments, however, of Alexandre, and those of Martin himself, have demonstrated clearly that the desired result is likewise obtained by the use of iron oxyd. In any case, to cause fining to take place, it is necessary that a certain proportion of oxyds of iron or manganese be present with the pig iron, added in the form of pure ore, roasted refuse, and rich scorias, or formed by oxydation in the furnace, even at the expense of the cast iron. All excess must, however, be avoided, lest the walls of the furnace be attacked.

As in the Bessemer process, we can conduct the operation according to two opposite methods: by fining completely and recarburizing by adding pure pig iron, or by

arresting the working when the metal is judged to be decarburized to the requisite degree.

The first method, as in the Bessemer process, by reason of its longer duration, insures a more complete purification, provided the recarburizer itself be pure, and the fining be continued some minutes after its final addition. This is the usual practice of Martin.

The pig irons worked at Sireuil are obtained principally from the blast furnaces of St. Louis, near Marseilles, and from Ria, near Prades. Those worked by Verdié are smelted from the ores of Bône. These are, as is well known, pure gray or white spiegel irons, containing manganese. Now, it is evident that all the irons used in the Bëssemer could be treated in this process, and also that even pig irons containing a small proportion of sulphur, could be worked by this means, especially if we operate by the addition of rich ores, and not simply by the reaction of wrought upon cast iron.

If superior quality be sought in the product, the malleable iron charged should itself be made from pure ores. This will be puddled iron, having more or less the nature of steel, and made from the pig metals of which I have just spoken. The ends of bars, and waste pieces from various sources, will be utilized, or, in their absence, muck bars of iron puddled for the purpose. But, for ordinary products, wrought iron and common scrap could be used, provided they are not too impure. We know that in the *run out fire*, and in puddling, we readily eliminate the greater part of the phosphorus of pig iron, and part of

its sulphur. Wrought iron thus once purified will give, when dissolved in pure pig iron, a homogeneous product in which the phosphorus and sulphur will be still more diluted. The steel, properly speaking, obtained by this means, will always be slightly short, it will lack body; but the soft homogeneous iron, even when impure, will still possess, especially, a tenacity very much higher than that of the same iron merely puddled, welded, and hammered. We could use, in part, pig irons of less purity than those adapted to the Bessemer process. We thus approximate Parry's method, which has been already mentioned, and to which I shall soon revert.

In the reverberatory furnace, as in the Bessemer process, and far more easily than in the latter, it is evident that we should be able to obtain, at will, every quality of steel comprised between the limits of white pig iron and wrought iron. We have but to vary the relative proportions of cast and wrought iron, or of cast iron and oxyd, as Alexandre has shown, and previously Réaumur, Clouet, Uchatius, and others.

Martin distinguishes in his patents four different products:

Mixed metal, which may be forged with difficulty, the ancient *Wildstahl* of the Germans, occupying an intermediate position between cast iron and ordinary steel.

Tool steel, or steel, properly speaking.

Mild steel, or homogeneous metal.

Cast wrought iron, which is red-short.

This division is insufficient; it would be preferable to

adopt the seven divisions of Tunner. Cast wrought iron is really *burnt* iron; it is red-short, because it has absorbed oxygen; it is converted into homogeneous metal by recarburation, by adding cast iron.

Mild steel, or *homogeneous metal*, comprises two very distinct products: *mild steel* proper, which is yet capable of being tempered (Nos. 5 and 6 of Tunner), and *homogeneous iron*, or No. 7 of Tunner.

The *tool steel* corresponds to Nos. 3 and 4.

The *mixed metal* corresponds to Nos. 1 and 2.

Let us now treat somewhat of the operation itself.

The furnace, heated white hot by the gases of the Siemens regenerator, is first charged with a certain weight of pig iron to be fined. This could be charged cold, but, to avoid chilling the furnace, it is preferable to heat the pigs previously, in the auxiliary furnace mentioned above.

When the pig iron is melted, and the bath very hot, the different kinds of iron of which I have spoken are charged in quantities of from 100—200 kilogrammes (220—440 pounds), each bar, package, or bloom weighing from 10—20 kilogrammes (22—44 pounds), and heated to clear redness. The additions are made every 20—30 minutes, and are followed by vigorous stirring, in order that the iron may be dissolved in the bath.

Instead of wrought iron, or with it, some rich ore may also be added, either in the crude state, roasted, or more or less reduced by cementation. But, as I have already stated, this manner of working is less easy. The mixture

is more difficult and the product less homogeneous, while the furnace is more strongly attacked.

It appears to me that it would be advantageous to make some slight additions of rich oxyd of iron. A more complete fining would certainly result from it. At all events, it is affirmed that the bed of scoria forming the surface of the bath becomes rapidly poor in iron, whether by the influence of the carbon of the pig iron, whether by the gases of the furnace, which may readily have a reducing reaction, or by the walls and hearth yielding up their silica.* The scoria obtained by Verdié gave the following proportions at the Assay Office of the École des Mines:

Silica	64.33
Alumina	8.66
Protoxyd of Iron	21.89
Protoxyd of Manganese	2.74
Lime	3.00
Total	100.62

It contained some metallic grains, but they were removed by means of a magnet before analyzing. The gain of the analysis, however, appears to indicate that it still contained some metallic particles. As in the Bessemer process, the silicate is poor, of a vitreous appearance, and more or less cavernous.

In this condition it could no longer act upon the bath

* When the heat is too low the slag is black and ferruginous, while it is of a light green color when the temperature is very high.

of pig metal as an oxydizing agent; it can remove neither sulphur nor phosphorus, but would rather yield up silica. Also, when the scoria becomes so lean, and while the fining is as yet incomplete, it is necessary to remove some of the scoria or enrich it by fresh additions of rich oxyd.

In all cases it is evident that the operation is under control; it may be suspended voluntarily, the proportions of wrought iron and oxyd added may be increased or diminished, to produce, at will, a more or less carburized metal, and this, too, with much greater ease than in the Bessemer process, because the operation is much slower, and numerous assays may be taken during its progress. The metal may even be taken out in an iron spoon, the contents poured into a mould, and the resulting ingot submitted to the forge-hammer. The specimen is broken cold, and the nature of the metal determined by its grain, its hardness, and its malleability. As I have previously stated, we can follow two distinct systems: decarburize gradually, and arrest the operation at the degree desired; or prolong it until the iron is burnt, and then recarburize by fresh additions of pure pig metal. The second method is preferable, for reasons already stated, and it is that finally adopted by Martin. Now, when the assays show the metal to be decarburized and sufficiently fined, pig iron heated to redness is charged, instead of the wrought iron or ore. After the metal thus added is melted and properly stirred, an assay is taken which determines the second amount of

pig iron to be added. When two or three similar charges have been made, assays are taken every half hour, until the desired metal is reached, when the charge is cast. Below are given the proportions of carbon obtained in four successive assays, made in my presence, by Verdié, after each fresh addition of 100—200 kilogrammes (220—440 pounds). The carbon was determined by bromine, and I have also made a comparative determination of it by the method of Eggertz, of Fahlun:

No. 1	contained	0.44	per cent.
No. 2	"	0.54	"
No. 3	"	0.76	"
No. 4	"	0.87	"

No. 4 is ordinary steel, of moderate hardness. No. 1 corresponds to decarburized iron. The other assays were made after successive additions of pig iron.

When we observe the bath in the course of the operation, a slight ebullition is apparent on the surface of the scoria. Bubbles of gas are disengaged, which result from the reaction of the silicate on the cast iron, and probably, also, from that of the silica of the hearth, which gives, in the presence of cast iron, carbonic oxyd and silicide of iron.

Properly speaking, however, no boiling takes place, nor any action resembling the *rising* of the molten charge in the hot working of the puddling furnace. Stirring is also indispensable, if a homogeneous product

is desired, and the gravest objection, in my opinion, to the new process, is the difficulty of producing homogeneous ingots. A stick of wood might be tried, as mentioned by Hassenfratz and Heath, and successfully employed with a similar object in copper fining. It would probably last almost as long as the iron paddle, and would create a more complete agitation.

An operation lasts from about seven to eight hours, when 3,000 kilogrammes (6,600 pounds) are treated. If necessary, therefore, three operations could be made in twenty-four hours ; but, as it is indispensable to clean and repair the hearth after each fusion, it is customary to make but one heat in a turn of twelve hours.

The relative proportions of pig and wrought iron vary with the nature of the product sought and the pig irons used. For steel proper, Alexandre found three of iron for one of pig iron, but he made use of a pig iron siliceous rather than carburized, and worked with crucibles, or in a reverberatory furnace, beneath a thick covering of vitreous slag, which was not oxydizing. When pure cast irons, of good quality, are worked with a mixture of wrought iron, and slightly oxydized scrap, the proportion of cast iron may be increased. In general, for ordinary steel, nearly equal parts of cast or wrought iron are taken, and the proportion of cast iron increased or diminished, according as steel more or less hard is sought.

Martin points out the following rules :

For his *mixed metal*, 1,000 parts wrought iron to 1,100—1,200 parts pig iron.

For *tool steel*, 1,000 parts wrought iron to 800—900 parts pig iron.

For *mild steel*, called *homogeneous metal*, 1,000 parts wrought iron to 700—750 parts pig iron.

The relative proportion of pig iron may be considerably augmented when some rich ore is used in part, instead of wrought iron.

From one-sixth to one-quarter of the weight of the pig iron above stated, is reserved for charging at the end of the operation.

The loss varies with the relative proportions of wrought and pig iron. It is greater according as the steel is lower. On an average it reaches six per cent. to eight per cent.

It is one-half the loss which is entailed by the Bessemer process. Thus, for this reason, also, the method by reaction merits the preference. In reality, however, it is necessary to add the loss undergone by the wrought iron in puddling to that of the reverberatory furnace. We would then reach a total loss of twelve per cent. to thirteen per cent., which would still leave, however, a slight advantage on the side of the new process. The expenses of puddling, however, must be added to the loss, so that if the superior pig iron, which is treated in the reverberatory furnace, or the Bessemer process, were subjected to that previous fining, the ultimate net cost would be greater than by the method of reaction. But the real advantage of the new method is the ability to utilize wrought irons made from the more ordinary

grades of pig metal, and which could not be directly fined in the Bessemer converter, for the manufacture of steel and homogeneous iron.

Puddling, when well done, eliminates from pig iron two-thirds of the sulphur and three-fourths of the phosphorus. It is an absolute purification, which is neither attained by the Bessemer process nor by the reaction method. The puddled bar, thus purified, is not dearer than superior pig iron,* and inasmuch as it results in the production of ordinary steel, we should be able to use common wrought iron in the method by reaction, as well as in the process by cementation and fusion in crucibles. Now, it is well known that for a great while ordinary cast steel has been made at Sheffield in crucibles, in the manufacture of which puddled iron was used, made from the English pig irons of Staffordshire and Yorkshire. The new process has the additional advantage of the ready utilization of the ends of bars, scraps, all descriptions of waste, old wrought iron, etc.

Let us, finally, remember that the proportion of wrought iron may be considerably reduced by using rich ore. This last mode of procedure has been followed in the reverberatory furnace, by Alexandre and Martin, as also in crucibles, by Uchatius.

To sum the matter up, however, the reverberatory furnace will not supersede Bessemer. The two processes have their reasons for existence; the one, on ac-

* From pig metal, costing 100 francs ($18.60) per *tonne* (2,200 pounds), we may obtain puddle balls at a cost of 140 francs ($26.04) per *tonne*.

count of the rapidity of its operation and the capital required, can only be suitable for large establishments, while the reverberatory furnace will be the tool of the shops, and is to be preferred when we desire to obtain, with ease, different kinds of steel, or experiment upon a small scale.

It now remains for us to treat of the net cost. I am not in possession of all the elements necessary to state it with exactness, and besides it varies according to the nature of the steel to be made, and the value of the wrought iron which reacts upon the pig metal. Below, some details are given.

On an average 1,100—1,200 kilogrammes (2,420—2,620 pounds) of good coal are consumed in both furnaces per ton of metal manufactured. The usual loss is six to eight per cent. upon the total weight of wrought iron and pig metal. The number of workmen is nearly the same as in the Bessemer process; the common labor is fifteen to twenty francs ($2.80—$3.70) per ton of metal produced.

The cost of keeping the furnace and other apparatus in order is less than in Bessemer works, as there is no blowing machine.

Repairs and periodic construction of the furnace would not cost 1,000 francs ($186) per month. Allowing during this period twenty to twenty-five operations of two and one-half to three tons each, the cost of keeping in repair will not exceed fifteen francs ($2.80) per ton. Accordingly, if we suppose the cost of superior pig iron to be 160 francs ($29.80), and that of the wrought iron added to be

170 francs ($31.60), which is high as an average, we will have, approximately, per ton of common steel in ingots:

540 kilogrammes	(1,188 lbs.)	pig iron.....	at 160 fr.—	86.40—($15.07)
540 "	1,188	wrought iron	at 170 fr.—	91.80—($17.07)
1,200 "	2,640	coal.....	at 12 fr.—	14.40—($ 2.67)
Labor.....				17.50—($ 3.25)
Repairs and Sundries.....				15.00—($ 2.80)
Total.....				225.10—($40.76)

a sum to which interest on capital, general expenses, royalty for patents, etc., must be added.

The preceding was compiled when Mr. Rinman, agent of the Bureau of Iron of Stockholm, had just passed some weeks at the forge at Sireuil, and communicated, with Martin's sanction, the following details of the new process:

The normal manufacture at Sireuil consists, at the present time (December, 1867, and January, 1868) of *homogeneous* iron, for gun-barrels, designed for the shops at Chatelleraut.

To obtain this product, 600—700 kilogrammes (1,320—1,540 lbs.) of mottled iron or white St. Louis lamellar iron are employed.

After fusion, 100 kilogrammes (220 lbs.) of puddled iron, made from a mixture of charcoal pig, from Lachat (Dordogne), and from St. Louis pig iron, are added at half-hourly intervals. The additions of wrought iron amounted to 1,200 kilogrammes (2,640 lbs.), and lasted during six hours. A *burnt* iron resulted, in which Mr. Rinman found only 0.1 per cent. carbon by the Eggertz method.

To effect carburation, about seven per cent. of the previous charge was added, viz.: 125—150 kilogrammes (275—330 lbs.) of St. Louis spiegel pig iron, whose composition I have given already. An hour after, the metal was cast, and an ingot obtained which contained 0.43 per cent. carbon.

In another operation, where only 1,100 kilogrammes (2,420 lbs.) of puddled iron were added to the 700 kilogrs. (1,540 lbs.) of pig iron originally charged, the carbon of the burnt iron was only 0.22 per cent., and that of the homogeneous iron, after 125 kilogrammes (275 lbs.) spiegel pig iron had been added, was only 0.37 per cent.

	Kilogrs.	Lbs.
Coal consumed in fusion furnace in one operation	1,340	(2,772)
And for previous heating of wrought iron	1,000	(2,200)
Total	2,340	(4,972)

Thus, for a total charge of wrought and cast iron of 2,000 kilogrammes (4,400 pounds), the amount of coal consumed is 2,340 kilogrammes (5,148 pounds), and 1,800—1,820 kilogrammes (3,960—4,004 lbs.) of ingots obtained. The common labor for such an operation costs, in addition, thirty to thirty-five francs ($5.60—$6.50). Accordingly, the elements of net cost per ton of ingots at Sireuil, the cost of wrought and cast iron not being included, are:

Coal	1,300 kilogrammes (2,860 lbs.)
Loss	9—10 per cent.
Labor	17—19 francs ($3.16—$3.53)

These figures differ but little from those which I have given above. They are, however, somewhat higher, which results from the fact that at Sireuil charges of two

tons only are worked, and also because homogeneous iron and not steel is the usual product, which involves a longer operation. An operation requires twelve hours, including the time necessary for repairing the hearth. I would add that the scoria at Sireuil is generally of a lighter color, contains less iron, and is less cavernous than that of Verdié, analyzed as above.

On December 18th, in presence of Rinman, an operation was conducted with the addition of ore. The ore was from Blanka (Ramsberg, in Sweden); it consisted of about sixty-eight per cent. of almost pure magnetic oxyd of iron. For the bath, 1,000 kilogrammes (2,200 lbs.) of mottled St. Louis pig iron was used, having been previously heated to redness. At the expiration of an hour and a half fusion was completed, and they proceeded to add ore in charges of 20 kilogrammes (44 pounds) in lumps of the size of a fist, or less. The ore was charged into the furnace cold, which to me appeared a mistake. The scoria became black and viscous almost immediately, and swelled up. Twice it was necessary to remove part of the silicate, to moderate its action. Altogether, 140 kilogrammes (308 pounds) of ore, and 600 kilogrammes (1,320 pounds) of puddled iron were charged. It was possible to commence recarburation at the twelfth hour only, by adding, as usual, 125 kilogrammes (275 pounds) of spiegel pig iron. The metal was cast at the end of the thirteenth hour.

The metal was good, but the furnace was more damaged than usual. That is the great drawback

in using ore. Homogeneity is also more difficult to attain.

	KILOS.	LBS.
The product consisted of ingots weighing.....	1,499	(3,297.8)
And waste.....	84	(184.8)
	1,583	(3,482.6)
Which, upon a charge of.....	1,125	(2,475)
And.....	600	(1,320)
Total.....	1,725	(3,795)

corresponds to a loss of eight per cent.

We thus see that the oxyd, notwithstanding its extreme richness, has yielded but little iron, and that it would be better to use heated ore reduced, wholly or in part, in a kind of Chenot furnace.

During the stay of Rinman, it was also attempted to replace puddled bars by the old rails of the Orleans Company.

With 500 kilogrammes (1,100 pounds) of lamellar white pig iron from St. Louis, and 600 kilogrammes (1,320 pounds) of old rails, the Eggertz method gave, in the small assay ingot, 1.27 per cent. carbon.

After charging 1,100 kilogrammes of rails (2,420 pounds), one-tenth per cent. of carbon was found. After recarburation with 50 kilogrammes (110 pounds) of spiegel pig iron, and after rolling the ingots, the product of homogeneous iron contained 0.25 per cent. of carbon.

Finally, using 100 kilogrammes (220 pounds) of pig iron for recarburation, 0.5 per cent. of carbon was found in the rolled product. Mr. Rinman has also determined,

in the same products, the proportions of sulphur by the Eggertz method.

The St. Louis pig iron contains an average of 0.04 per cent. of sulphur; the homogeneous iron for gun-barrels contains 0.02 per cent.—0.025 per cent. sulphur. One-half of the sulphur, therefore, is found to be removed, but rather by puddling than in the fusion furnace, at the moment the wrought iron reacts upon the pig metal, which is proved by the assays made of the products obtained from the Orleans old rails.

The latter contain 0.1 per cent. sulphur, while the product in ingots, from 500 kilogrammes (1,100 pounds) of pig iron, and 1,100 kilogrammes (2,420 pounds) of rails, contains 0.075 per cent. sulphur.

	KIL.	LBS.
Now, 500 kilogrammes (1,100 pounds) pig iron, containing 0.04 per cent. sulphur, give	0.20	(0.44)
And 1,100 kilogrammes (2,420 pounds) rails containing 0.1 per cent. sulphur, give	1.10	(2.42)
Total sulphur contained	1.30	(2.86)

On the other hand, the 1,450 kilogrammes (3,190 pounds) of metal cast, containing 0.075 per cent. of sulphur, contain 1.09 kilogrammes (0.5 pounds) of sulphur only, or less than one-sixth, is found to be eliminated in the reverberatory furnace.

A final experiment was made with pig iron from Aubin, containing 0.2 per cent. of sulphur, and some old rails from Orleans. A very hot-short homogeneous iron was obtained. It is apparent that substances containing sulphur are no more adapted to this than to the Bessemer

process. The sulphur should be removed in the blast furnace and in puddling, or in the *run out fire*. Possibly, however, a measurable success would result from using rich ore, as in the experiment mentioned above.

Manufacture of Refined Cast Iron.

A new product remains to be treated of, which at present occupies a position between ordinary pig iron and cast steel. This is *refined* cast iron, in which Martin's *mixed* metal is included.

We know that pig irons are, in general, less tenacious and softer, according as they contain a greater proportion of earthy metals and silicon. This is the cause of the softness and want of tenacity of Scotch irons. This condition of things is changed by a more or less complete elimination of the foreign elements. Simple remelting in a cupola, and especially fusion in a reverberatory, will produce partial purification; whence the superiority of irons of a second melting. This may, however, be improved upon.

In England, toughened cast iron (*fonte tenace*) is obtained by remelting ordinary cast iron with small pieces of iron, in the proportion of twenty to forty per cent. This is exactly the process by reaction, of which I have just spoken; but as less wrought iron is added than at Martin's works, a product is obtained which is intermediate between his *mixed* metal and common cast iron. When pure pig iron is submitted to this operation, a highly

tenacious semi-decarburized product is obtained, which hardens when cast in an iron chill mould. Wrought iron may be placed in the moulds. The molten pig iron forms a paste with the wrought iron, and the mixture is remelted, either in a cupola or a reverberatory. A similar product may be obtained by remelting gray pig iron of first fusion, with a certain proportion of fine metal, or superior fined pig iron.

Refined pig iron (*Feineisen*, or *Reineisen*) is made at Königshütte, in Silesia, by remelting good gray iron in a reverberatory, under the action of a forced air-current.

This is an actual fining which purifies the metal. Pig iron for rolls is treated in this way. It retains very little silicon.

For several years some German works have supplied railway companies with car-wheels and crossings of hardened cast iron (*Hartguss*), which is very durable. The same establishments manufacture cono-cylindrical shot from this metal, whitened and rendered hard on the surface. They appear preferable to steel shot. The mode of manufacture is secret, but it is more than probable that this *mixed* metal is obtained by one of the methods of which I have just spoken, especially by the one which consists in mixing the cast and wrought irons. In all cases, hardened refined iron may be produced by the methods in question. The German works which furnish this hardened cast iron, under the name *Gruzon metal*, are those of Buckau, near Magdeburg ; a foundry at Bude, in Hungary, and a works recently established at

Königsberg. At the Exposition of the Champ de Mars, the works of Buckau exhibited some shot, and other pieces of casting. The iron is gray or mottled at the centre, fibrous and silvery white at the edges. It is evident, from the fractures, that the metal is a medium between cast iron proper and steel. The increase in price of the hardened Königsberg iron over ordinary cast iron is 80 francs ($14.88) per ton.

I have determined the carbon in *Gruzon* metal by the Eggertz method. Three specimens from the Exposition were at my disposal; two fragments of bars, and one-half of a cono-cylindrical shot. Splinters of the whitened iron only were selected from the surface of the specimens. No. 1 could be filed. No. 2 was cut with difficulty, and the file failed to make any impression upon the shot. It was necessary to pulverize the splinters of the two latter irons, in a hard steel Abich mortar.

The assay showed the following proportions:

No. 1	2.15	per cent. carbon.
No. 2	2.24	" "
The iron composing the shot	2.40	" "

These proportions appear to indicate that Gruzon metal is a more or less decarburized pig iron. In other respects, it is a very pure iron. I found in it 0.02—0.03 per cent. of sulphur only.

Cast irons and steels may be improved by combining them with small proportions of tungsten and titanium.

The effects of tungsten have been particularly investigated by Koeller and De Mayr in Austria, Leguen and Caron in France, and in England by the younger Mushet. Tungsten increases the tenacity and hardness of cast iron and steel. The hardness of steel increases to an almost indefinite extent with the proportion of this metal added ; at any rate, the proportion of 10 per cent. may be exceeded. As regards tenacity, it increases with as much as 2 or 3 per cent., beyond which it decreases. The metal becomes short when charged too highly with tungsten.

The cast irons made experimentally by Leguen have been analyzed at the École des Mines. The specimens contained from 2 per cent. to 10 per cent. of tungsten. The resistance to transverse rupture was increased in the proportion of 37 to 56 or 57, with from 2 per cent. to 4 per cent. of tungsten ; from 37 to 62, with from 5 per cent. to 7 per cent. of tungsten ; and from 37 to 50 or 55, with from 8 per cent. to 10 per cent. of tungsten.

Experiments have been made with Gartsherrie iron. Square bars were cast 0.60 m. (23.6 inches) long, by 0.05 m. (1.97 inches) on a side. They were supported at the ends, and the pressure applied at the centre and carried to rupture. It was ascertained that beyond 3 per cent. to 4 per cent. of tungsten, there is no advantage gained by increasing the proportion.

Notwithstanding the advantages which appear to result from the quantities just quoted, the use of tungsten does not appear destined to increase very much. It is diffi-

cult to obtain a perfectly homogeneous product. Besides, De Mayr, of Léoben, who has manufactured tungsten steel for a considerable time, has lately abandoned it, because he observed that in the successive heatings necessary to work the steel, and even when cold, the tungsten becomes gradually oxydized to the centre of the bars, which destroys the superiority of the steel.

Among the products exhibited by De Mayr, on the other hand, was a *manganese* steel. I hasten, however, to add that I am informed, by that skillful manufacturer's agent himself, that the steel in question did not contain a trace of manganese. I have already called attention to the fact that this metal renders steel rather short. It enters, however, into all methods of fining as a purifying agent, since its oxyd is not retained by silica. Let us add that refined cast iron, and especially cast steel obtained by reaction, are sometimes subjected to prolonged re-heating. This softening is advised by Réaumur. It may be re-heated in a closed vessel, which destroys its crystalline structure, and separates a portion of its carbon as graphite; or better, decarburized by cementation, as in the malleable cast iron works. Both processes diminish the shortness at the same time with the hardness, without, however, sensibly increasing the tenacity, properly speaking.

IV.

METHODS FOUNDED ON CEMENTATION.

WHEN it is desired to purify cast iron, as completely as possible, the fining must be prolonged till iron is reached, and then steel obtained by recarburation. This is the method pursued by Bessemer and Martin in their direct treatment for cast steel. But as the recarburation is effected in this case by cast iron, a portion of the impurities contained in it are replaced in the ultimate product. If pure steel is sought, the recarburation should be effected by charcoal or pure carbonaceous reagents; this is the principle of *cementation.* Hence, it obtains that, when steel was only required for fine tools, cementation was frequently considered the only method capable of producing true steel, and wrought irons of superior quality as being alone suited to its manufacture. This view would be a just one, were *superior* steel only to be called *steel.* But, in the same manner that all varieties of *irons* and *pig* irons—from the most tenacious to the softest—are called wrought and pig irons; as I stated at the beginning of this memoir, the name *steel* cannot be denied to the whole series of malleable products consisting of iron which may be tempered; and this, whatever be the degree of their fineness, hardness, tenacity, etc. Thus, by cementing superior irons, superior steel will be obtained; and by cementing common irons, com-

mon steel will be obtained. It is, however, very evident, and cannot be too often repeated, that a purer steel will always be obtained from a given pig iron by fining it for wrought iron and converting the product, than by fining the same pig iron directly for steel.

Cementation may have a double object; we may be satisfied with simple carburation, or carburize and melt in the same apparatus. Simple cementation without fusion is effected in chests and furnaces by the usual method. I shall speak here of the theory only, upon which point we are far from agreed.

As regards carburation and fusion combined, it is a process recommended toward the close of the last century, by Chalut and Clouet* in France, and by Mushet in England; it has, however, been little used on a large scale, except within twenty or thirty years. Ordinary crucibles are used, or better, a special cupola, according to Parry's method. On this head we may refer to the method of recarburation attempted by Bérard, in his double tuyere furnace. (p. 79.)

Ordinary Cementation.

Iron may be carburized in a great many different ways; pure carbon, ordinary charcoal, solid carburets, coal, and even, in general, all substances, animal and vegetable, may be made to react upon wrought iron.

* *Journal de Physique*, year 1788, p. 46, 2d part, and *Journal des Mines*, Vol. IX.

Solid or gaseous cyanides may also be employed, and almost all gases and vapors containing carbon, such as carbonic oxyd and numerous carburets of hydrogen. Whenever wrought iron is heated to a red heat in presence of any of these substances, it becomes carburized, at first on the surface, and afterwards, by degrees, to the centre. In what manner and under what circumstances is this carburation produced, and of what nature is the carburet obtained? Such are the problems which several chemists have endeavored to solve. Let us review their investigations, taking some recent researches by Margueritte as our chief guide.*

Fremy makes a distinction between simple carburation and conversion into steel. According to this savant, the co-operation of nitrogen is necessary to obtain steel; but we have already seen the part which this gas really performs. It is true that it is found in very small quantities in most irons, steels, and pig irons. Irons and pig irons, however, contain as much of it as steels, and in no case does a fixed relation exist between the corresponding proportions of carbon and nitrogen—nothing which denotes a true nitro-carburet compound.

But. is nitrogen even necessary as a vehicle, as in the judgment of Saunderson? Does nitrogen, which may exist in very minute proportion in all irons, form cyanogen with the carbon? and may not this carbon unite with the iron except as cyanogen or a cyanide? In short, does the nitrogen in the iron, or that from another source,

* *Annales de Physique et de Chimie*, 4th Series, Vol. VI., p. 55 (year 1865).

perform the part of a vehicle by uniting itself with the carbon for the purpose of yielding it again to the iron?

Margueritte's experiments prove that nitrogen does not really enter into steel, either as a vehicle or as a constituent element. Let us proceed to details regarding this point.

The early experiments appeared to establish the fact that the presence of nitrogen was not necessary to carburize iron; but as earthen vessels were used, objection could be made to this, on the ground that the atmosphere of the furnaces would supply the gas in question. It became necessary to experiment anew, taking fresh precautions. This, Margueritte did in the following manner: he selected porcelain tubes, glazed within and without, which renders them, according to Deville's experiments, absolutely impenetrable by the furnace gases.

In the first series of experiments, Margueritte verified this impenetrability; then he proved that pure iron, obtained from the oxalate, may be as well carburized by carbonic oxyd as the irons of commerce, in which traces of nitrogen may be suspected to exist. To experiment successfully, the gaseous current must not, however, be too slow. If the carbonic acid produced be not quickly removed, by carbonic oxyd in excess, it may again oxydize the carbon which has just united with the iron.*

The carburation of the pure iron obtained from oxa-

* Laurent and Leplay did not effect the carburation of wrought iron by carbonic oxyd. (*Annales de Physique et de Chimie*, 2d Series, Vol. LXV., p. 403. Stammer, a German chemist, had proved it, however, as early as 1851. (*Berg werks freund*, 1851, p. 388.)

late answers another objection made by Caron. This skillful chemist had proved that silicide of iron is converted into silica and carburet of iron by the influence of carbonic oxyd, and, accordingly, he believed that to this fact was attributable the decomposition of this gas in the irons of commerce, when containing a small amount of silicon.

Silicon, in fact, is rarely absent, but when chemically determined, it is apparent that it is not proportionate to the weight of carbon separated by the iron from carbonic oxyd. In his experiments, Margueritte, however, was unable to exceed the degree of carburation corresponding to steel, and seemingly he admits that cast iron could not be obtained by this process. He is deceived in this, since Stammer has succeeded, by causing carbonic oxyd to act for eight successive days upon wrought iron; and, on the other hand, if carbonic oxyd is really *decomposed* at a high temperature, its action should be the same as that of pure solid carbon. Now, the latter transforms iron into a carburet, as the following experiments prove.

To establish the fact that carbon cements iron, without the assistance of any other element, we must work as in the case of carbonic oxyd, in vessels which are impermeable by gases.

Margueritte placed a thin plate of wrought iron in a doubly glazed tube, and upon the iron, which rested upon the edges of a porcelain boat, he placed a diamond. Before heating the tube, he passed pure dry hydrogen through it for several hours, to expel all the oxygen

which might form carbonic oxyd. He afterwards heated the tube for some time, and, after cooling, opened the apparatus. The thin iron plate was pierced as with a punch, and a carburized wrought iron globule was found cast in the boat. In another operation, diamond powder was placed in a porcelain capsule, one end of a piece of iron wire plunged into it, and the whole was heated equally, in an atmosphere of pure dry hydrogen. The portion only of the iron plunged into the powder was carburized, while the remainder was not affected. We may then reject the theory of the volatility of carbon, which is admitted by Laurent, and it is apparent, finally, that carburation is equally effected by solid carbon and carbonic oxyd, although with less rapidity, especially by the latter, than by the gaseous compounds, hydro- and nitro-carburets.

These last experiments prove, besides, that nitrogen is not necessary for this carburation by pure carbon. Hydrogen, in fact, according to Fremy himself, removes nitrogen from iron ; so that, if this element were an indispensable constituent in steel, conversion into steel would be impossible, in the experiments I have just quoted, in which the carbon and iron are surrounded by an atmosphere of pure hydrogen.

Cementation by solid carbon is also a result of the early experience of Réaumur, already quoted (p. 82). When a wrought iron bar is plunged into a molten cast iron bath, the iron is cemented by degrees, beginning at the surface. We also know from the practice of Verdié,

at Firminy (Loire), that molten steel, poured upon wrought iron raised to a red heat, unites with it by welding, yielding to it a little of its carbon. Margueritte has, besides, proved that carbon really passes from one molecule to another, as Gay Lussac had already proved, in 1846, contrary to Leplay's hypothesis.* When an iron bar of moderate thickness is slightly cemented by any method (gas or solid coal), the exterior alone is carburized, while the centre remains unaffected. But if the bar is immediately heated for a considerable time, surrounded by an atmosphere of hydrogen, the carbon will be seen to advance gradually from the surface toward the centre, so that the iron, after cooling, will be slightly carburized in all its parts. This movement of solid molecules, which was for a long time denied, appears to belong to the series of facts discovered by Tresca in his interesting experiments on the fluidity of soft bodies.

Let us bear in mind, however, that when iron is thus carburized by any of the methods just quoted, steel or cast iron may always be obtained at will. It is a question of temperature and time, excepting that the duration of the operation, and the heat required, vary with the nature of the carburizing compound. Finely divided charcoal, bi-carbide of hydrogen, cyanogen and cyanides carburize more rapidly than carbonic oxyd and charcoal in small pieces.

As a result of the facts I have just enumerated, the theory of cementation in chests appears to me easily

* *Annales de Physique et de Chimie*, 3d Series, Vol. XVII., p. 223.

established. In these chests the iron is in the presence of charcoal, oxyd of carbon, and slightly carburized hydrogen. Each of these substances contributes its share towards the carburation. The carbonic oxyd acts as a vehicle of communication. It is decomposed by the iron and then returned to the state of oxyd by the charcoal. This action is always slow, and the carburation is chiefly effected by solid charcoal. But does no other reaction take place with this? Alkaline cyanides are known to be formed in blast furnaces, and even generally in every process in which charcoal acts upon carbonate of potassa and nitrogen at a red heat.

But wood charcoal always contains carbonate of potassa, and nitrogen, also, is present in cementing chests. Cyanide of potassium will be formed then, which itself acts as a vehicle. The iron decomposes the cyanogen, and the potassium liberated, again forms a cyanide. A portion, however, is lost by volatilization; thus, in time, the charcoal in the chests is found to be deprived entirely of alkali, and it then loses, in part, its original efficacy as a carburizing agent. It is, in fact, well known that the old cement is never as effective as that which is fresh; and if it has lost a little of its carburetted hydrogen in a previous operation, this circumstance alone does not seem to me sufficient to explain the difference in the action of the two cements.

Margueritte denies the formation of cyanides in the cementation chests.* He inclines to believe in the inves-

* Margueritte admits that the alkaline ashes, and also baryta and lime, in

tigations of Cailletet, who found nitrogen, hydrogen, and carbonic oxyd in the gases which escape from cementing chests, but no cyanogen nor cyanides.* I appreciate the accuracy of the analyses, but not that of the conclusions which Margueritte draws from them. Cyanogen and cyanides are too readily decomposed in the presence of wrought iron to withstand its influence.

It is the potassium, and not the cyanide, which is volatilized. For the rest, it is well known that cyanides and alkaline ferro-cyanides are very energetic cementing agents, and that they have long been used in the arts in the conversion of iron into steel. I cannot receive Margueritte's theory, which denies the formation of cyanides, nor that of Caron, who assures us that carbon cannot be made to combine with iron, except by means of a gas.† The truth lies between the two. In my opinion, according to what precedes, the cementation practised in steel works is chiefly effected by charcoal in a solid form, but also results from the carburizing action of several gases, with which cyanide of potassium has, very probably, just combined.

Before closing this somewhat long discussion upon the causes of cementation, allow me to take up again some rather bold assertions made by Fremy.

This savant affirms that the old theory does not ex-

cementing chests, do not form cyanides and remove from the iron only the sulphur which it may contain (p. 83 of his memoir). If this were so, the alkaline substances would remain without any effect in cementing pure iron, and in such cases, the old cement would not lose its efficacy.

* *Comptes rendus*, Vol. LX., p. 344.

† *Comptes rendus*, Vol. LII., pp. 638 and 680.

plain the existence of blisters in cemented steel.* This would be true, if the bar iron were perfectly pure. But who is not aware that in forges the best iron always contains some scoriaceous particles, which shingling has not expelled? Now, when carbon penetrates into the bar, it reduces the silicates, and sets free the carbonic oxyd, which separates the bars and produces blisters; and this is so true, that soft irons, which contain, by their nature, the least carbon, and, consequently, more oxydized particles, are similarly covered with more numerous and larger blisters.

Fremy also assures us that steel cannot be made from irons containing phosphorus, sulphur, and silicon, because it would be impossible to nitrogenize them.† That impure irons cannot furnish a tenacious steel, is evident; but to affirm that their carburation, or conversion into steel, in cementing chests, is impossible, would be as incorrect as to pretend that pig irons cannot be obtained from ores containing sulphur, phosphorus, or silica. The error is the result of the unjust distinction which Fremy has always endeavored to establish between the terms carburation and conversion into steel, while, in reality, I cannot repeat it sufficiently often, the operation is one and the same, always producing, according to the length of the operation, the temperature in the chests and the nature of the carburizing agent, at first steel and afterwards cast iron. The important point is to conduct the

* *Comptes rendus*, Vol. LII., p. 627.
† *Comptes rendus*, Vol. LII., p. 635.

operation slowly enough to give the carbon time to penetrate to the centre of the bars, without over-carburizing the exterior. I would add, with Margueritte, that the actual process of cementation fulfills this end. This is not what we should seek to modify. The problem to be solved is, rather, how to produce good iron with any ore whatever. Now, in this respect, much remains to be done; not only we do not know how to purify iron, but we do not even know the special influence which each foreign element exerts upon the essential qualities of iron, steel, and pig iron.

The sulphur is sufficiently eliminated by roasting the ores, or smelting, with an excess of limestone. By fining, also, manganese and silicon are removed, and even a portion of the phosphorus, when the irons are fined or puddled, in the presence of very basic scorias. But the purification is never perfect, and the means especially defective, when it becomes a question of the elimination of some other substances, such as copper, nickel, and arsenic. In conclusion, then, it still remains true to say, that good steel cannot be obtained unless pure materials be used.

Cementation and Simultaneous Fusion in Crucibles.

Chalut and Clouet made steel, as early as the last century, by melting iron with one to two per cent. of powdered charcoal.

About the year 1800, Mushet took out a patent as

inventor of the same method of manufacture. Since then several manufacturers have made cast steel on a large scale by this process. I will especially mention Fénéon and Frichou as having made the application of this process as early as 1830, at the works of Rives, at St. Étienne. The filings and turnings of iron or steel from the fire-arms factory were melted in crucibles, a small quantity of wood charcoal being mixed with them. The establishment has been in successful operation for twenty years. It is true the steel was not of the first quality, but its net cost was low. Other manufacturers on the Loire have also applied and do still apply the same method for the utilization of various refuse, such as crop-ends of bars, clippings, etc. Ordinary steel is thus produced.

In 1839 William Vickers, of Sheffield, and Heath, both claimed patents for the direct manufacture of cast steel. The former used one hundred of wrought iron turnings, three peroxyd of manganese, and three of wood charcoal; the latter a mixture of wrought iron, carbonaceous substances, and one to three per cent. carburet of manganese.

In 1856 Joseph Bennet Howell claimed a patent for the production of mild steel, which he called *homogeneous metal*, from a similar mixture. Finally Naylor and Vickers have manufactured, for several years, almost exclusively homogeneous iron and ordinary steel, either by the method of reaction or by directly melting small pieces of iron with two per cent. of powdered wood charcoal. Their establishment contains 144 double crucible

furnaces, each crucible being charged with twenty-four to twenty-five kilogrammes (52.8 to 55 lbs.) of metal.

From this hasty review it appears that the manufacture of steel by cementation and simultaneous fusion has really become a practical process. All kinds of wrought iron may thus be treated, but the quality of the steel depends, of necessity, upon that of the irons used.

Farrar, an American metallurgist, asserted some years ago that by means of certain mixtures (chiefly composed of alkaline cyanides), he could not only rapidly carburize and melt irons, but could purify them and obtain a good steel with any wrought iron. His Excellency the Minister of Public Works intrusted Rivot and myself with the task of witnessing Farrar's experiments, and of testing the steels produced. As might have been expected, we found that good irons produced good steels, and also that ordinary irons produced an inferior steel, which was brittle both cold and hot. Here, then, a process for purifying remains likewise to be discovered.

To sum the matter up, direct fusion in crucibles is a simple process and of easy application, but it is difficult to attain a degree of carburation as definite as by melting, by the old method, a mixture of blister steels carefully selected when removed from the chests.

Cementation and Fusion in a Cupola—Double Fining. (Parry Process.)*

Cementation and simultaneous fusion in crucibles cannot give good products unless the irons themselves are pure. But what is impossible to attain by a single operation, may become possible, to a certain extent, by a *double* or *triple* fining.

This is the principle of the Parry process. The ordinary English pig irons contain phosphorus and sulphur; they can neither be converted into merchantable steel by reaction, nor by the Bessemer process. The sulphur and phosphorus remain, in great measure, in the final product. But when these irons are puddled in a bath of basic scorias, the expulsion of the greater part of the two elements is effected; this is, at present, a well-established fact. Parry affirms that he has often proved at Ebbw Vale that the sulphur is by this means reduced to a third of its original proportion, and the phosphorus to a fourth or a fifth. The figures may be disputed; they necessarily vary with the mode of working; but the absolute fact of partial purification is not to be doubted.

The iron thus purified by puddling is recarburized in a cupola three to four metres in height (9.84—13.12 feet) by 0.50—0.60 metres (1.64—1.97 feet) in diameter. By using pure coke and excess of lime a white iron is obtained, containing two or three per cent. of carbon;

* English patent of November 18th, 1861; No. 2,900.

this is fined for steel. This latter operation should be conducted according to the process of Martien, of Newark, of which the Ebbw Vale Company has become the proprietor for the United Kingdom.* Various obstacles have, however, caused the Bessemer converter to be adopted for the latter working. The present method of operation at Ebbw Vale is as follows :†

"The ends of bars, clippings, puddle balls, and wrought iron from all sources are recarburized in the cupola which I have just mentioned. To facilitate working, a certain proportion (generally an equal weight) of good hematite pig is added. The product flows directly into the Bessemer converter, where it is fined for iron, with final recarburation, by addition of manganese pig iron, according to the method generally pursued. The product is sufficiently tenacious to be rolled into rails and T irons. It is a common steel or ordinary homogeneous iron, but which, however, from the very fact of its homogeneity, will always possess more tenacity than the same iron piled and welded in a reverberatory."

It appears, then, that Parry's method, like working by reaction, and better than the latter because of the double fining, allows of the utilization of pig and wrought irons of ordinary quality for the manufacture of common steel.

It is true that recarburation and double fining increase the cost. The net cost of Parry steel would exceed that

* English Patent of September 15th, 1855; No. 2,082.

† Manuscript Notes of Michael Lévy, Student-Engineer of Mines.

of Bessemer, if similar materials were treated. But the advantage of the new process is the facility of fining cheaper irons than the Bessemer process requires.

In order that homogeneous iron and cast steel may supersede the ordinary welded rolled iron on railways, and in large works of construction, it is a necessity not to be compelled to use pure ore exclusively. Every method which does not treat ordinary ores will remain of limited application, and will soon become obsolete. The Bessemer process, as practised at present, is unfortunately in this condition. It requires pure pig irons. A remedy for this exists in Parry's method, and in part in the Martin process. This, in my opinion, is the chief advantage in the new methods. The solution of the problem is neither complete nor radical. The complete purification of ores or pig metals will probably never be realized. We must be content with mere expedients. Now, the new process already allows materials of less purity to be used for steel, than those which have been usually employed up to the present time. A new path is open to progress, and one which, in my opinion, possesses the great advantage of not superseding all existing methods. Puddling furnaces will still be employed. By the old process ordinary ores are converted into puddle balls, and these puddle balls may be recarburized, to a greater or less degree, by reaction in the Martin reverberatory, or by fusion in the Parry cupola.

But is puddling absolutely necessary? An effort should be made to replace it by simple fining in the low

hearth, or in the reverberatory furnace beneath a bath of basic scorias. The metal thus refined by a first working could be at once recarburized in the Parry cupola, or even charged with choice ores in the blast furnace. The principle of *progressive* purification, operating alternately by oxydation and recarburation, appears to me pregnant with results.

The example being given, the problem to be solved is how to follow it, for the pure ores will be speedily exhausted if the ordinary ores are not used. Besides, it is evident that the question may be of more various application ; I have no doubt also that practical men will soon devote themselves to numerous trials in this direction.

A single observation before closing. Bessemer, Martin, and Parry steels have of late been rolled into rails in a large number of works, and railway companies appear to require chiefly hard steels for their manufacture. This is well, if the pig irons be pure, as in Sweden and Austria ; I believe it to be a mistake when ordinary pig metal is treated. A rather soft steel, and almost a homogeneous iron, is required to prevent the rails being brittle. If it is impossible to unite tenacity and hardness, tenacity should rather be sought at the expense of hardness.

Method of Prof. Eggertz, of Fahlun, for the Determination of Carbon in Steels.

In the present condition of iron manufacture, the determination of the proportions of carbon in steels has become a necessity. I have just shown in the preceding pages that the classification of Bessemer steels, in Sweden and Austria, depends upon the proportion of carbon they contain, and that, in the Martin process, it would be very useful to determine with rapidity the proportions of carbon in the small steel ingots taken out during the different phases of the operation.

The usual methods of analysis, based upon the combustion of the carbon or upon the solution of the iron by bromine, iodine, chloride of copper, etc., are long and delicate operations. They are not to be thought of for the laboratory of an iron works. A more expeditious but yet sure method has become necessary. That invented some years ago by Prof. Eggertz, of Fahlun, appears to me to fulfill this twofold condition; the inventor presented a model apparatus to the École des Mines, Paris,* and with its aid I have been enabled to apply the new method, and verify for myself the constancy of its results when the operation is conducted with care. I think it may be recommended to steelmakers in France; and to facilitate its adoption I will

* This apparatus was exhibited last year among the products of the Swedish Exposition in the Champ de Mars

describe it in some detail, based upon experiments I have myself performed, and using as a guide Eggertz's own memoir, translated from the Swedish in Kerl's and Bornemann's German Journal of Mines (year 1863, p. 369).

The Eggertz method is a colorimetric process, founded upon the use of standard solutions. It is based upon this fact: when carburet of iron is treated with nitric acid, slightly diluted and warm, the combined carbon is converted into a highly-colored organic product, while the graphite is not attacked. By dilution, the solution may be brought to the strength of a *normal* solution obtained from a steel of known composition, and the proportion of carbon in the metal assayed is then determined by the volume of its solution.

The operation is thus conducted: Pure nitric acid is used; that the iron solution may not become yellow, it should be free from chlorine. The acid is diluted to 1.20 density, which corresponds to 24° of Beaumé's areometer.

The solution is effected in a small glass tube, 0.10 m. —0.12 m. (3.9—4.7 inches) in length, by 0.010 m.—0.012 m. (0.4—0.5 inch) in diameter. The amount of the substance taken is 0.10 gramme of filings, in a state of fine division, having previously been passed through a metallic sieve, whose meshes are less than 0.004 m. (0.16 inch) in diameter. For this 0.10 gramme of filings, 1.5—2 cubic centimetres of acid, of 24° of Beaumé, are required, if the steel contains but little carbon, and 4—5 cubic centimetres, if the proportion of carbon is large, as, for instance, in the case of white iron.

When the acid is poured into the tube containing the filings, or the latter are placed in the acid, solution of the iron is effected almost immediately, attended with effervescence. Black flocks appear in greater or less abundance, suspended in the iron solution, which must be effected with the aid of *heat*, for the reaction is slow, or almost nothing, in the cold. It is, besides, necessary to work constantly at the same temperature, and under the same conditions. To this end, the tube in which the solution is made is heated in a water-bath, at 80° C. For this purpose I employed a porcelain crucible, 0.07 m.—0.08 m. (2.8—3.2 inches) in height, and containing 0.025 m.—0.030 m. (0.98—1.2 inches) of water, and into this the test tube—or even two or three tubes, for several operations may be easily conducted at the same time—is plunged, together with a thermometer. A small gas jet, or the flame of a spirit-lamp, allows the degree of heat to be controlled without sensible variations. The black flocks are then seen to dissolve by degrees, with evolution of gas, and the solution darkens in proportion. After three hours, solution is complete; the evolution of gas ceases entirely. The solution is cooled by plunging the tube into cool water; it is then poured into a burette, graduated to tenths of a cubic centimetre. Finally, it is diluted with pure water, by means of a pipette, until its color is exactly the same as that of the standard solution. For exact comparison, the normal solution should be in a tube of the same diameter as the burette, and made of the same glass. The similarity of the two colors

will be judged by comparing their transparency against the daylight, or, better still, by placing both tubes before a sheet of white paper, properly illuminated by diffused light.

Thus, with some experience, a degree of exactness may readily be attained, which is measured by 1—2 tenths of a cubic centimetre in volume, which indicates the proportion of carbon within 2—3 hundredths of a per cent.

The normal solution is, in fact, obtained by measuring as many cubic centimetres as the type-steel contains thousandths of a per cent. of carbon. Now, in practice, this is a more than sufficient approximation, since the proportion of carbon varies 0.25 per cent. in passing from one number of hardness to another, according to Tunner's scale.

To obtain coincident results, some precautions are, however. necessary.

The solution should always be made with the same acid, and at about 80°, as I have mentioned above. The shade grows lighter, if the solution is heated for two or three hours above 80°, and the color becomes a little too dark, when the operation is performed at a temperature below 80°. By keeping the water-bath at about 80°, constant results are easily obtained. Several times the same steel, in two or three successive operations, has shown exactly the same proportions of carbon, within one or two hundredths of one per cent.

Eggertz also observed that after some days the colors

became lighter. The results should be compared the same day the assay is made, and the normal solution often renewed, which is not difficult, since several assays may be made at the same time. It is only necessary to have a *type-steel* at hand whose proportion of carbon has been determined accurately by the usual methods. If a similar specimen, for instance, contains 0.75 per cent. of carbon, it will only be necessary to treat 0.10 gramme, as I have just stated, and to dilute the cold solution in a burette until its volume is 7.5 c.c. This will be the normal solution of which each cubic centimetre corresponds to one-tenth of a per cent. of carbon. A normal solution may, however, be prepared which may be sufficiently protected from daylight by means of sugar slightly burnt, dissolved in alcohol, diluted with an equal bulk of water. The apparatus from the Exposition, now at the École des Mines, contains a color such as this, in a tube sealed by a lamp-flame, and protected in a case from the daylight. By means of the type-steel in the same apparatus I have been enabled to prove that the alcoholic preparation had retained most of its strength, although made six or eight months ago. The color, however, had become a little lighter, but the shade was nearly the same as that of the nitrate solution of the steel.

If, at the close of the operation, after decanting the solution into a burette, any small black particles are observed at the bottom of the glass tube, two or three drops of the same acid of 24° Beaumé are added, and heat applied by means of a lamp.

If nothing is set free the particles are graphite, which is insoluble in the acid in question. In all cases, some drops must be added to the solution in the burette before pouring in the pure water to make the determination.

The method I have just explained only gives the *combined* carbon; this is, however, generally sufficient, since in iron establishments Bessemer ingots, or the tests in the Martin process, are the chief subjects of assay. Now, in both cases the chilling of the metal is sufficiently sudden to prevent the separation of a notable quantity of combined carbon. In any case in which it is desired to determine the graphite, it would be sufficient to dissolve five to ten grammes of the steel under consideration in diluted nitric acid, and to continue the operation until all evolution of gas has ceased. The insoluble residue is graphite, mixed with a little silica. After filtering and weighing, the carbonaceous matter should be incinerated, with the object of subtracting the weight of the silica from it.

When the proportion of carbon in steels is very small, 0.1 to 0.4 or 0.5 per cent., for instance, as in homogeneous irons, the solution obtained may be of a lighter color than the normal solution. It suffices, in such cases, to dilute the latter so as to obtain a new standard solution, in which each cubic centimetre corresponds to one-half or one-third of a tenth of one per cent. of carbon. The Eggertz method is applicable to pig irons, but is less accurate according as the proportion of combined carbon is greater. I will mention, in closing, that, to

verify the Eggertz method, I have analyzed by bromine two tests of the Martin process, from Verdié's establishment, of which I have spoken on page 102. No. 3, taking 17.128 grammes, gave 0.129 gramme, or 0.76 per cent. of carbon, which is the proportion found by the Eggertz method.

No. 4, taking 14.662 grammes, gave 0.1295 gramme, or 0.88 per cent. of carbon, whereas I found 0.86—0.87 per cent. by the Eggertz method.

I have also assayed the spiegel pig from St. Louis, of which I have given the analysis on page 17. I found 4 per cent. of carbon, while the analysis in question shows 4.04 per cent.

I will finally recur to the fact that, if carbon is the element upon which the hardness and tenacity of steel depends, it should not be forgotten that other substances greatly modify the qualities of that metal. We should not require from the Eggertz method more than it can give. It does not allow a comparison of two steels of different origin. Sulphur, phosphorus, copper, silicon, etc., cannot in this case be neglected, as steels may contain them. But in one establishment, where similar materials are habitually treated, the steels made should differ but little from each other, except in the proportions of carbon they contain, and, in such cases, the Eggertz method may be especially useful.

Determination of the Sulphur in Steels and Pig Irons.

Professor Eggertz has also turned his attention to examining steels and pig iron for sulphur. The result of his labor appeared in Swedish, in the *Annales du Comptoir de Fer*, of Stockholm, in 1860, and was translated in 1862 into German, in Kerl's *Berg und Hütten Männische Zeitung*, p. 88.* I extract what follows from the German journal.

Eggertz proved, at an early day, as Rivot† also remarks, that dissolving irons in aqua regia does not cause all the sulphur to pass into the state of sulphuric acid, and that the presence of nitric acid is a hindrance in the subsequent operations. The Swedish scientist prefers an aqueous solution of chlorate of potash, to which hydrochloric acid is added by degrees. By keeping the solution constantly boiling, Eggertz is confident that no sulphuretted hydrogen is set free.

For five grammes of metal in the state of filings or fine powder,‡ passed through a sieve whose meshes are less than 0.0004 m., ten grammes of chlorate of potash are taken, dissolved in two hundred cubic centimetres of water.

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* Rinman has just translated this article into French in the *Annales des Mines.*

† *Docimasie*, Vol. III., p. 541.

‡ The pig iron is reduced to powder in a steel Abich mortar.

Hydrochloric acid of 1.12 density is poured into the boiling aqueous solution containing the metallic filings, at first drop by drop, and then, by degrees, more rapidly, until sixty cubic centimetres are contained in the solution. From half an hour to forty minutes are required to effect solution, after which the solution is evaporated to dryness in a water-bath to drive off the excess of reagents. It is then treated with a little acid and water, and filtered; the sulphuric acid is now determined with the usual precautions in the filtrate, by means of chloride of barium.

This method of analysis, however, is long, and time is often lacking in iron establishments.

Eggertz then sought a more rapid process, which would afford approximately, without pretence to perfect accuracy, some useful indications of the amount of sulphur in pig irons, wrought irons, and steels. The basis of the process is the more or less darkened shade, yellow, brown, or blue, developed by the separation of slight traces of sulphuretted hydrogen upon a silver plate.

Into a bottle, with a ground-glass stopper, 0.025 m. (0.98 inch) in diameter, by 0.15 m. (5.9 inches) in height, one gramme of water and 0.50 gramme concentrated sulphuric acid (say 1.33 c.c. acid of 1.23 density) are poured, then 0.10 gramme of metal in fine powder (passed through a sieve whose meshes are 0.0004 m. in diameter) is introduced into the same flask, and a piece of thin silver plate is immediately plunged into the upper part of the flask, the silver plate being held by a fine

platinum wire retained between the neck of the flask and the glass stopper.

At the ordinary temperature of the room the iron dissolves in fifteen minutes at least, so that the plate may be removed for examination at the expiration of this time.

The following is the scale of colors, arranged by Eggertz, as the result of numerous experiments :

No. 1 represents the white shade of the newly scoured trial plate, composed of 75 silver and 25 copper.

No. 2 represents the yellow shade of a standard alloy, which may be obtained by fusing 60 of copper with 40 of tin.

No. 3 represents brown tombac, which a mixture of 85 of copper and 15 of zinc gives exactly.

No. 4 represents the dark blue of a properly tempered watch-spring.

The same numbers, followed by one or more tenths, correspond to the intermediate shades. By comparing these shades with the proportions of sulphur, determined accurately by the method of analysis above mentioned, Eggertz has been enabled to prepare the following table :

No. 1	corresponds to	0.00	per cent.	Sulphur.
No. 1.2	"	0.01	"	"
No. 2	"	0.02	"	"
No. 2.5	"	0.03	"	"
No. 3	"	0.04	"	"
No. 3.1	"	0.05	"	"
No. 3.2	"	0.06	"	"

No. 3.3	corresponds to	..... 0.07	per cent.	Sulphur.
No. 3.5	"	..... 0.08	"	"
No. 3.6	"	..... 0.09	"	"
No. 3.7	"	..... 0.10	"	"
No. 3.8	"	a minimum of 0.12	"	"
No. 3.9	"	" 0.15	"	"
No. 4	"	" 0.20	"	"

It is evident that these values cannot be exact, and that to catch exactly the shades comprised between Nos. 3 and 4 is especially difficult. With some experience, however, the estimation of proportions below 0.10 per cent. is sufficiently near for practical purposes.

To insure success, some precautions are necessary. The silver foil should be newly cleaned each time, upon a leather strop, sprinkled with a little fine sand. The foil should be held in the forceps, and not in the fingers, and should be wiped *dry* with filter paper. Care must be taken not to touch it again with the fingers, in introducing it into the flask, and to suspend it vertically, in the plane of the diameter of the flask, or the two sides would be colored unequally. The operation should not be conducted at a temperature greater than 30°, or the foil will be covered with little drops, and the coloration be irregular. Finally, to judge of the colors, the assay foil should be exposed to diffused light, upon a table covered with white paper, side by side with the standard shades (Nos. 1, 2, 3, and 4), and compared under a lens.

The numerous experiments undertaken by Eggertz, regarding the proportions of sulphur contained in

wrought irons, steels, and cast irons, have furnished the following results:

Wrought iron, of the best quality, frequently has not the least effect upon the silver foil; as, however, the sulphur is unequally distributed, the experiment must be repeated upon different parts of the same bar.

Steely iron, which has been melted, may give shade No. 3 (or 0.04 per cent. of sulphur), and still allow readily of being punched hot, while certain irons, merely hammered, may crack under the same test when hot, though only containing 0.02 per cent. of sulphur, designated by shade No. 2.

The favorable influence of homogeneity due to fusion, is here apparent. In the first case, the metal is not red-short, though it contains 0.04 per cent. of sulphur, while the oxydized, or imperfectly fined particles, not expelled by shingling, render the iron sensibly red-short in the second case, though the proportion of sulphur is less.

Iron from a good English rail gave 0.11 per cent. of sulphur. It could not be rolled into small bars. The edges cracked when hot.

Fine steels, of the best repute, do not color the silver foil above No. 1.5; they contain, therefore, less than 0.02 per cent. of sulphur.

Pig iron is rarely free from sulphur. Most Swedish irons give shades Nos. 2—3. The Finspong gun irons reach Nos. 3.3—3.7; or 0.07—0.10 per cent. of sulphur. Since the proportion in pig irons does not ex-

ceed No. 3, fining will produce, without difficulty, iron which is not red-short; or, even if it is red-short, it will be due to another element. But when the shade approaches deep blue (No. 4), the wrought iron will almost always be brittle when hot.

As to the distribution of sulphur, Eggertz confirms the now old observation, that it is more abundant towards the top of the pigs than at the bottom, and that it is generally distributed in pig irons irregularly.

To obtain a value for small proportions of sulphur in an iron ore, it may be reduced in a brasqued crucible, and the button subjected to the method of assay just treated of. It is necessary, however, that the scoria be very siliceous, otherwise a portion of the sulphur is retained by the lime. Thus, the same ore gave in the button, 0.09 per cent. sulphur, when reduced with 15 per cent. quartz; 0.04 per cent. with 5 per cent. lime; and 0.01—0.02 per cent. only with 2 per cent. lime. It is also necessary to make sure of the absence of sulphur in the brasque and limestone. The assay of the brasque is made by simply melting pure iron in the brasqued crucible, and subjecting the button obtained to the method for determining sulphur. As regards the limestone, it is melted in the brasqued crucible, with pure iron, and an equal weight of a mixture composed of about 0.6 gramme dry clay and 0.4 gramme lime.

ADDITIONAL NOTE.—I stated, on page 140, that we should not require more from the Eggertz method than it can give. I called particular attention to the

Explanation of Plates.

Plate I. Oscillating roller consisting of cylindrical sectors put in motion by means of connecting rods.

Fig. 2. Plan of roller and motor engine.

Fig. 1. Vertical section perpendicular to axis of roller.

Fig. 3. Elevation parallel to axis of roller.

Fig. 4. Section of motor cylinder.

m. Motor cylinder.

l'. Piston rod.

pp. Connecting rods of upper sector.

O. Connecting rods of lower sector.

n. Cross-piece or head uniting the connecting rods with piston rod.

fact, that if the qualities of steel depend chiefly upon the proportion of carbon which they contain (page 25), other elements likewise modify the tenacity, hardness, etc. The Eggertz method cannot be used to compare steels obtained from different materials. In such cases, it is necessary to make a complete analysis, and to record all the elements. These conclusions have just been confirmed by an experiment made at Neuberg.

Tunner wrote to me from Vienna, under date of February 29th, that a coke iron had, very recently, been experimentally treated at Neuberg, by the Bessemer process. The steels obtained corresponded, in physical properties, to No. 3 of Tunner's scale. It was a good ordinary cast steel, very hard, difficult to weld, while, according to the proportion of carbon it contained, it was only No. 6.

When more completely analyzed at Vienna, 0.3 per cent. of carbon, at most, was found, as by the Eggertz method, but as a compensation for this, nearly 1 per cent. of silicon.

From this example, it is apparent that, to a certain extent, silicon may replace carbon in steels, as in pig irons. It is a further proof of the continuity of the series—pig iron, steel, and wrought iron. Still, supported by the practice in forges, I believe I may affirm that pure carbon steels are, nevertheless, greatly superior to silicon steels, aluminium steels, etc., in which the iron holds other elements besides carbon in solution.

D. Sector containing the upper grooves.

C. Sector containing the lower grooves.

C^2 and D^2. Points of attachment of the connecting rods.

Plate II. Oscillating rollers consisting of cylindrical sectors put in motion by means of racks.

Figs. 1 and 2. Represent the roller with single rack.

Fig. 1. Vertical section perpendicular to axis of roller.

Fig. 2. Vertical section parallel to axis of roller.

K. Cylinder receiving water under pressure, to enable the direction and extent of stroke to be changed at will.

j''. Piston rod.

jj. Single rack.

j'j'. Friction rollers supporting rack.

ii. Toothed sector, fastened like a crank to one end of lower roll cylinder.

C. Lower grooved sector.

D. Upper grooved sector.

The latter are connected by the toothed arcs C', D'.

Figs. 3 and 4. Represent roller with double rack.

Fig. 3. Vertical section perpendicular to axis of roller.

Fig. 4. Vertical section parallel to axis of roller.

m. Steam cylinder.

l'. Piston rod.

l. Double rack.

C and D. Grooved sectors.

C' and D'. Toothed segments worked by the rack.

Plates III. and IV. Haswell's Forging Press.

Plate III., Fig. 1. Represents plan of press and motor apparatus.

Plate IV. { Fig. 1. Elevation of press. Fig. 2. Vertical section through axis of press.

a. Steam cylinders furnishing pressure.

k. Mechanism putting in motion the steam cylinder slide valves.

c.c. Piston rods of cylinder a, which form the plungers of the two aspirating and force pumps p.

t.t. Aspiration pipes of pumps p.

r.r. Receiver to regulate the working of the pumps p.

t'.t'. Pipes to conduct the water forced back into the body of the press P.

P. Body of press of cast iron, with the two superposed cylinders, in the lower of which the forging-piston G moves, and in the upper the counter-piston C moves, which serves to raise the piston G.

f.f. Connecting rods joining the pistons G and C.

Q. Anvil stock supporting the body of the press by means of four iron columns.

d. Pipe making communication between the reservoir l and the press P.

s.s. Valves with rods designed to open or close communication between the pumps p and the forging press, and between the press and the reservoir l.

i.h. Levers for working the above valve rods. The levers are put in motion by small steam cylinders, not drawn in the plan.

l. Reservoir receiving water from the press when

the forging piston is raised. This reservoir is divided into two parts by a piston. It supports the water just spoken of while the steam operates upon the lower surface.

m. Reservoir furnishing the pumps p with feed-water. It receives at the same time the overflow of the apparatus l.

The working of the apparatus is as follows:

The forging piston G being at the end of its stroke, and the forging being in position upon the anvil, with the dies to give it the proper form, the valves ss are disposed so as to open communication between the reservoir l and the cylinder of the forging press; the steam is then caused to act upon the lower surface of the piston in the reservoir l; the forced water causes the forging piston G to descend rapidly until it is in contact with the dies or the forging. The position of the valves ss is then changed to open communication between the press and the pumps pp, and the engine a is made to act until the required degree of compression is obtained.

The position of the valves ss is again changed; the pumps raise again the counter-piston C, and the larger piston G forces the water back in the reservoir l.

The forging is replaced, and the same operations recommence.

In the machine constructed by De Mayr of Léoben the pressure of water was 405 kilogrammes per square centimetre (576079.7 pounds per square inch); accordingly, a total pressure of 764 tonnes (1684329.7 pounds) was obtained upon the large piston of 49 centimetres (19.3

inches) diameter. Piston rods, heads of connecting rods, parts of wrought iron wheels, etc., are thus forged.

Plate IV., Fig. 3, shows a drawing of Bessemer's forging press. It is simpler than the Haswell press, and is composed of a cast iron housing or frame, A, like that of a large roll. It has a powerful cast steel screw, BB, which acts upon the upper surface of a heavy mass, C, of cast iron, arranged in the same manner as a pestle-hammer, and, like it, sliding on the guides of the housing. The hammer has a face, as usual, or is faced with a die, D. It is suspended by a strong rod, ff, from a counterbalanced lever, which raises the hammer, when the screw ceases to act. The rod ff passes through the axis of the screw, which is bored throughout for that purpose.

The forging, E, is placed upon the anvil-face, F. The latter is movable, and resembles the large reversing piston in the Haswell press.

It consists of a heavy piston, 60 centimetres (23.6 inches) in diameter toward the upper part, and one-third or one-quarter as much at the base.

A groove cut throughout the length of the lower cylinder allows the water to act upon the double base of the piston G.

The water is forced directly by the piston J, by means of a powerful steam-engine. When it is desired to use the press, the hammer C descends to a distance from the anvil a little greater than the thickness of the forging, and the pump J is made to work. If the steam-engine is provided with a heavy fly-wheel, the apparatus may, at

will, be made to act by slow pressure, or by a kind of sudden pressure or shock.

In the first case the hammer C descends to the forging, and the pressure is perceptible when the engine is put in motion. In the second a certain interval is left between; the piston J then pushes the large piston G with increased swiftness, and at the instant when the piece E comes in contact with the face D there is a shock and a violent pressure, owing to the action of the fly-wheel of the engine. By lowering the hammer C successively by means of the screw D, it is possible to forge or draw out as with the ordinary hammer. In the machine constructed by Bessemer, a pressure of 1,000 kilogrammes per square centimetre (141935.5 lbs. per square inch) is realized upon the anvil, which is sufficient to forge steel by slow pressure.

Plate V. Ramsbottom's Double Hammer, with Single Motor Engine.

Fig. 1. Vertical section of double hammer, with single motor engine.

Fig. 2. Plan of double hammer.

Fig. 3. Transverse elevation on UV of plan (2).

Fig. 4. Transverse elevation on XY of plan (2).

aa. Represent both hammers, supported on rollers, bb, moving on rails, cc.

Both hammers are simultaneously put in motion by the steam-engine, consisting of the cylinder d, piston d', cylindrical valve d^2, etc.

The piston-rod is fastened to a cross-head moving in

guides, and the cross-head is itself united with the hammers by double connecting rods E'. The iron axis a^4 passing transversely through the hammer, and supporting the connecting rods, has leather piled on each surface, and greased to soften the rebound caused by the hammer strokes. The valve d^2 is worked with the lever d^3, whose extreme positions are indicated by dotted lines. The stop-valve d^4 is opened and closed by the lever d^5.

A stop, d^6, is fastened to the cross-head of the piston-rod, which raises the lever d^7 when the piston reaches the highest point of its stroke. Another cleat may similarly act automatically upon the lever d^7, to cause reverse motion. In general, however, the stroke of the hammer is limited by means of the hand-lever d^8.

The ingot to be hammered, g, is placed in the cage i, itself supported by the frame i^2, which may be raised or lowered at will by means of the lever i^3, and the rods and counterpoise, i^5 and i^6. The frame i^2 moves in guides, i^4.

The frame, and, consequently, the ingot to be hammered, may thus be moved horizontally around its axis. For this purpose the wheel with handles, j, is used, which communicates with the frame by means of rods and levers, j^2, j^3, j^4, j^5, j^6. When the wheel j turns 90°, the ingot describes the same angle.

The ingot to be hammered may then be raised, lowered, or turned to the right or left, at will.

Plate VI. Bérard's Steel Furnace.

Fig. 1. Longitudinal section.

Fig. 2. Transverse section on XY of Fig. 1.

A and B represent the sheet iron wagons which support the hearths. They may be raised by means of screws after being placed in position. The hydraulic joint ab prevents the escape of hot gases.

CC′ show the two basins in which the cast iron is fined.

DD are the inclined hearths upon which the pigs are charged.

G is the open brickwork furnace filled with coke. It has a charging-hopper closed by a water-joint.

EE are the annular tuyeres which conduct the combustible gases and hot air.

ii represent the slopes through which the burnt gases pass to the chimney.

In F (Fig. 2) is shown the rack supporting the inclined tuyere, by which the air intended to cause fining and the purifying and recarburizing gases is forced into the bath of pig iron.

N represents the system of boxes, valves, and pipes which allow the direction of the gaseous current to be reversed.

Plate VI. Heath's Steel Furnace.

Fig. 3. Plan.

Fig. 4. Vertical section on XY of plan.

Fig. 5. Transverse section on UZ.

A represents the cupola in which the pig iron is remelted. It flows into the steel furnace C, through the canal KK. The hearth, BB, heated by the waste heat of

the furnace C, extends to the right and left of the canal KK. In it the wrought iron intended to react upon the pig metal is heated. The charging is effected through the door D. A hot-blast oven, I, is placed in the waste-heat chimney of this furnace, which supplies the tuyeres mm by the pipes HH; these tuyeres are annular. The heated air enters through the central conduit; the gas from a generator passes into the annular space surrounding the air-tuyeres, through the pipe GG.

E, charging door of steel furnace.

F, casting hole.

The wrought iron accumulated in BB is pushed into the furnace C when the cast iron is sufficiently heated. This is effected through the door D, whose situation is not in all cases very convenient for the work.

Plate VI., Fig. 6. Ramsbottom's Direct-Acting Double Hammer. The hammer is connected with a motor piston.

Plate VI., Fig. 7. Ramsbottom's Direct-Acting Double Hammer. The hammer is connected with a motor cylinder.

APPENDIX.

THE BESSEMER PROCESS

IN THE

UNITED STATES,

WITH A DESCRIPTION OF THE

CHARACTERISTIC AMERICAN

PLANT AND MACHINERY.

APPENDIX.

BESSEMER PROCESS IN THE UNITED STATES.

American Type of Bessemer Plant.

The American Bessemer plant, although it was, at the time of its introduction into the United States, superior in many details of arrangement to that employed in England and on the continent of Europe, has since been so modified as to embody at the present time the best features of existing works abroad, as well as many original improvements which have been suggested and fully developed by practice. These improvements, which give to the American plant a character distinct from that of Bessemer works elsewhere, consist mainly, as will hereafter be shown in detail, in the enlargement and strengthening of some of the parts, and, especially, in the entire rearrangement of the machinery and buildings, the result of which changes is that the manufacture of Bessemer steel is facilitated and the yield of a given plant aug mented, while the cost of production is decreased ; thus making the success of the process assured, and giving to it the impetus which has caused the erection of many new works, commenced during the past year, chiefly

in the West, where the supply of suitable ore and coal for making Bessemer iron is boundless.

Plate VII. is nearly a copy of the Bessemer works of the North Chicago Rolling Mill Company, and the works of the Joliet Iron and Steel Company. It also illustrates generally the converting department of the works at Troy, Harrisburg, Newburgh (near Cleveland, Ohio), Bridgeport (South Chicago), Johnstown, and Bethlehem. The cupola buildings of the last-named works vary considerably, those at Johnstown and Bethlehem being included under the converting house roofs.

Fig. 1 is a ground plan of the converting, engine, and boiler houses, and a plan of the twenty-five feet floor of the cupola building.

Fig. 2 is a ground plan of the cupola building, and Fig. 3, a plan of the thirty-seven feet, or cupola charging floor.

Fig. 4 is a section at AB of Fig. 2, showing the cupolas and their ladles in elevation.

Fig. 5 is a section at EF of Fig. 1, showing a side elevation of the cranes, converters, cupolas, etc.

Fig. 6 is an exterior end elevation of the buildings.

It will be observed that the ground floor of the works (unlike the English works) is all on the same level, excepting only the ingot-pit, which is two feet six inches deep; that it is accessible from all sides, and that the engine and boiler house is at the side of the converting building, leaving the ends open for the *through* passages AB and IJ.

The Melting Department.

The first feature of this system to which our attention is drawn, is the method of conducting the charging and melting, and the convenience of the arrangement of parts peculiar to the American practice. The hoist for coal and refractory materials is placed at one end of the cupola building, the iron hoist being at the other end, instead of placing two common hoists side by side. By this disposition more room is allowed in the yard for storing and handling materials, and keeping the different supplies separate.

Three sides of the cupola building are available for this purpose.

The kind of hoist most convenient and durable consists of a hydraulic cylinder, whose stroke is one-half the distance traversed by the hoist, the connections being as usual by a chain and two sheaves, one of which is fixed to the piston-rod. The advantages of this hoist over others, especially the belt hoist, are, that it is simple in construction, requires few repairs, is uniform in its motion, and completely under control, while there is no danger to be apprehended from broken belts.

The charging of the pig iron and coal is done by means of small four-wheeled iron wagons, with swiveling front wheels, each wagon holding one ton of pig metal, or 1,500 pounds of coal, or less, as required. These wagons are small, light, and easily drawn and manœuvred on flat floor plates by one man. Larger railway wagons or cars

have been elsewhere employed for charging; but the turn-tables, switches, and other complications, and especially the short railway curves incident to their use, render them objectionable. On a small charging floor, and a necessarily contracted charging ground, they are difficult to manœuvre without interfering with one another. Six one-ton wagons for iron, and six coal wagons, will supply iron, coal, limestone, sand, ganister, and other material sufficient to melt 100 tons of metal per twenty-four hours. Another unquestionable advantage of the small wagons is, that they allow of an intimate mixture of irons in the cold state, with greater convenience than by any other means. Six or more different kinds of pig iron are thoroughly mixed in each wagon before charging.

Cupolas are used in this country exclusively for melting the gray iron, instead of reverberatory furnaces: the use of cupolas—less conveniently arranged, however, —is extending abroad. The cupola is cheaper to construct and to maintain, and in it, from five to six pounds of iron are melted with one pound of coal. The cupola melts more rapidly also, and with greater heat, because the coal and iron are in direct contact, whereas in the reverberatory furnace the melting is accomplished by the flame alone. Any impurities which may exist in the coal or coke used in the cupola have not been found to affect the iron injuriously, so far as experience in this country has shown. Cupola furnaces also occupy vastly less room than reverberatory furnaces, and require a less expensive building.

The ordinary foundry cupolas were used at first in Bessemer steel establishments, but were not successful. The changes which have adapted them for use in steel works, chiefly consist in increasing the depth from the tuyeres to the tap-hole, from the previous dimension of one foot to three or four feet; in doubling the sectional area of the tuyeres, and in reducing the projection of the boshes. The dimensions of the cupolas are very nearly as follows: Height, 14 feet; interior diameters of an elliptical cupola, 6.5 feet and 3.5 feet. The aggregate area of the six tuyeres is 200 square inches. Instead of elliptical cupolas, circular ones of the same cross-sectional area are sometimes employed. The method of charging the cupolas is as follows: The bed of the charge is formed of 5,400 pounds of fuel, upon which are charged the contents of three wagons containing from 1 to 1¼ tons of pig metal each. A second bed of 1,400 pounds of fuel is then charged, and three more wagon-loads of pig iron added. These alternate charges of fuel and iron continue until the cupola is filled, and it is kept thus filled to the charging door for from eight to ten hours. A small quantity of limestone is also added, which acts as a flux. The cupolas will melt 100,000 pounds of iron in nine hours' consecutive working, and will hold five tons during the few first charges; but as the hearth becomes filled with slag the capacity is decreased, and the furnaces require to be tapped more frequently. The iron is tapped from the cupolas directly into ladles (K, Figs. 1, 4 and 5), standing on scales. These ladles have a capacity of

twelve tons each, so as to hold two six-ton charges if necessary. The object of interposing ladles between the cupolas and the converters, instead of tapping the metal directly into the converters, is: first, that the gray iron charges may be accurately weighed, and the spiegeleisen charges to be added, thus definitely ascertained; and, second, the convenience of holding the metal, if the vessels are not ready to receive it; whereas, if ladles were not used, the cupola hearths would soon become filled with metal, and the melting would have to be suspended.

These improvements in the cupola and its accessories have been largely contributed to by Mr. John B. Pearse, Manager of the Pennsylvania Steel Works, at Harrisburg.*

The cupolas have usually been blown by Root pressure blowers. The Sturtevant fan blower has recently been introduced, with great success, at the Troy Works. It has been found that a No. 8 Sturtevant blower, making 2,500 revolutions per minute, will give a pressure of one pound per square inch, which is ample for all require-

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* I am indebted to Dr. Robert H. Lamborn, the distinguished metallurgical author, for the following information, relative to important changes, soon to be perfected, in the character of the new Bessemer Plant of the Pennsylvania Steel Company:

"The Pennsylvania Steel Company are about erecting new works, upon a plan arranged by their Manager, Mr. John B. Pearse, and patented by him. Four converters will be used, two of which will be continually in a position to undergo repairs at a distance from the casting pit. Two converters will always be in place, ready to receive the molten metal.

"By this means, steady work can be continued night and day, in two vessels, and the amount of metal that can be turned into steel in the works vastly increased."

ments, and, indeed, is to be considered a remarkable result for a simple fan.

The inclined cupola dump, L, Plate VII., Fig. 5, is conveniently situated with reference to the cinder mill, Fig. 2, in which the cinders which slide down the incline are ground up, so that the "shot" iron may be saved and re-melted. The usual method of dumping the cinders from the cupola into a confined space, requires them to be quarried out and broken up before passing to the mill; whereas, in the arrangement shown in the drawing, they fall without the wall of the building, where water may be thrown on them, by means of a hose, and, being thus speedily cooled and disintegrated, they are taken to the mill with the least expense in handling.

It will be observed that the space in the cupola building is utilized by placing the cupola charging floor over the ladles. Were it placed on the other side of the cupolas, a considerably greater width of building would be required. The molten metal is conducted from the cupola ladles, K, Fig. 5, into the converters by means of inclined runners. The upper and steeper portion of the runner, M, Fig. 5, is fastened at one end to one of the ladles by a hinge joint, while its lower end is free to move back and forth upon rollers. It thus has a vertical and a horizontal motion, according as the cupola ladle is in position to receive metal from the cupola, or is lowered to allow the metal it contains to flow into the runner. A similar runner is attached to the other ladle, and both

discharge into the stationary trough, N. This trough receives the metal and conducts it, by one of its two branches, into either converter, as required. See also Plate IX., Fig. 10. The runners have such a steep fall (the spiegeleisen and cupola furnace floors being twenty-five feet above the general level), that the metal, by reason of its rapid descent, passes clean into the vessels without leaving a "skull."

The spiegeleisen furnaces are shown in plan in Fig. 1, and in cross-section, in Fig. 4, Plate VII.; they are charged from the floor, P, Fig. 1, and tapped from the opposite side. Reverberatory furnaces are preferable to cupolas for melting spiegeleisen, because the charge may be kept hot in them for a longer time, while it is apt to chill in the bed of a cupola. This use of the reverberatory furnace for spiegeleisen is not universal, cupola furnaces being used in some works with fair results. The form of reverberatory used for spiegeleisen in American works differs somewhat from that used in the English Bessemer works, in that the charge is placed near the bridge, the bed being sloped downward from the bridge. In the English furnaces, the spiegeleisen is placed near the flue, and the slope of the bed is downward from the flue toward the bridge.

The former furnace thus prevents the rapid oxydation of the manganese, because the heated gases, containing no free air, are reverberated from the roof upon the charge, while, in the latter furnace, the charge is melted with greater rapidity; but the manganese of the spiegel-

eisen is liable to be oxydized by the direct impingement of free air.

The engine which drives the fans supplying blast to the cupolas and spiegeleisen furnaces, is placed beneath the charging floor of the spiegeleisen furnace, Fig. 2, which space would otherwise be unoccupied. This engine also drives the cinder mills, which have been previously referred to. At the end of the converting building, opposite to that in which this engine is situated, a large space is left for grinding and mixing the refractory materials, for lining vessels, ladles, etc. This space is sufficiently large to supply refractory materials for two or three pairs of vessels, and consequently, need be added to but one plant of the series. The ganister, in the massive state, is hoisted by the coal-lift to the twenty-five feet floor, and there dumped into a chute, which conducts it to a Blake crusher, standing on a high frame, whence the material falls into crushing rollers, and from these rollers it passes into the mixing mill, in which the fire-clay, and other materials to be added to the ganister, are placed. The whole mass is mixed dry by power, and is then moistened, as required, for linings and bottoms, on the general level of the works. The fire-clay, ground brick, and other refractory materials, are similarly prepared, and may be stored in the vaults, under the mixing floor, for future use. Between the walls on which the cupolas stand, considerable spaces are left, which are utilized as store bins for coal, clay, tuyeres, charcoal,

and other materials required for current use in the Bessemer building.

A gangway, AB, Fig. 2, 10 feet or more in width, runs entirely through the cupola building, on the ground floor, in front of the bins, so that these materials may be readily put in the bins by means of carts, or narrow-gauge dumping cars, which saves much handling, in comparison with storing these materials in underground vaults. It will thus be seen that, although the cupola building is not large, it has a very large amount of available and convenient storing capacity, and all the space in it is well utilized. Where everything in the melting department stands on one or two levels, as in England, the building must be very large; the distances between the furnaces and the converters, and between the bins and the places where the materials are used, are great, while the operations interfere with one another; whereas, in a high building, with several floors, one above the other, the operations are simple, and the materials are more conveniently stored. In such buildings, thorough ventilation is secured, by lantern roofs and windows placed on every side. The height of the cupola building, above the other buildings, thus allowing this free ventilation on all sides, is an important feature.

Converting Department.

In the English works, designed by Mr. Bessemer, and rigidly followed in England and on the Continent, the

converting vessels are placed on opposite sides of the casting pit, thus greatly diminishing the available space for casting; and the working space around the pit and under the converters is sunk below the general level, which is inconvenient and wasteful of room.

Fig. 7, Plate VIII., is a section, and Fig. 8 a plan of the usual type of English Bessemer plant. The ingot-pit, D, is contracted, as compared with E, Fig. 1, Plate VII., and the standing, or platform, around it, E, Figs. 7 and 8, Plate VIII., is several feet below the general level, K, on which the cranes stand, and the bottom of the pit is nine or ten feet below the general level. A very limited working space is thus afforded in and about the pit, and the heat is excessive. There are but two cranes around the ingot-pit, with which it is impossible to handle the ladles, moulds, ingots, etc., for a large product.

One of the most important and distinguishing features of the converting department in American works, and one which is followed in all of them, is the placing of the vessels side by side, and raising them above the general level. The ingot casting pit is also enlarged, and there are three cranes around it. The sunken pit, the limited space, and the great heat, are all avoided in the American plant, by raising the vessels so that there is a distance of nine feet from the general level to the centre of the vessels, and arranging them as shown in Plate VII. Another advantage over previous arrangements, is the second working floor, or platform, extending around the converters, by means of which all parts

of the vessels may readily be reached, and materials be taken to the nose of the vessels, as they lie in a horizontal position. The runners resting on this platform, and which convey the molten metal into the vessels, may be readily reached to be moulded. Beneath this platform there is ample head-room, and space outside of the ingot-pit for removing and working at the vessel bottoms, while there is no corresponding space in the English plant. Thus, by this arrangement, there are two working levels instead of one, the lower of which is the general level of the building, instead of being a hot and contracted pit. Still another advantage is, that this platform, from which the vessels are fired and their bottoms examined, is the nine feet floor of the cupola building, Fig. 4, Plate VII., which is accessible to the coal-hoists by the passage Q, Figs. 1 and 4. These operations, therefore, do not interfere with any of the other operations in the Bessemer building. The next advantage of this arrangement is, that it brings the chimneys out of the way of the cranes. By an inspection of the English plant, Plate VIII., it will be seen that, if the cranes swing over the vessels, they strike the vessel chimneys, and thus their range is limited; while, if they do not swing over the vessels, other means of lifting the vessels must be provided. In the American plant the two side ingot cranes, R and S, Fig. 1, command the vessels, the pit, and all the floor-room over which they swing.

The centre ingot crane, T, commands the pit and a large floor-space, and all the cranes swing over the rail-

road, IJ, which is carried across the pit for this purpose, or it may be curved around it if preferred. All the ingots are removed as fast as produced, by cars entering at I, and passing over the ingot scales in the weigh-house, at J.

Placing the vessels side by side is not entirely new, the same arrangement having been adopted in Sir John Brown and Company's three-ton plant, at Sheffield, although not in a manner to realize any of the advantages of the American method. The vessels are not raised to a higher level, nor is the casting pit raised, and there is no means of reaching the vessels in the rear, and consequently the arrangement of vessels side by side is less convenient, under the circumstances, than the present English system. Sinking the casting pit and ladle crane as deep as is done in English works requires much deeper excavation, and sometimes costly blasting. The apparatus for rotating the converters is equally convenient in English and American works. In the earlier American works the rotating cylinder is vertical and below the vessels, while in the latest plant it is vertical, but above the vessels, so as to be perfectly accessible.

Plate IX. represents a front elevation, Fig. 9, and a plan, Fig. 10, of the arrangement of vessels and their accessories at the Pennsylvania Steel Works, Harrisburg. In the newer American works some details are improved and the piers behind the vessels are of iron instead of brick. In the Cambria Steel Works at Johnstown, Pennsylvania, these piers are removed, a common roof ex-

tending over the converting and cupola departments. The two adjacent trunnions of the vessels rest in standards, and carry the pinions by which they are rotated. The outer trunnions receive the blast, and rest each on a beam. The beam has sufficient span to allow the whole bottom of the vessel to be removed laterally beneath it, which vastly facilitates the lining of the vessels and putting in new bottoms. Indeed, it is superior in these respects to any method previously employed. One end of the beam rests in the cupola building wall, and the other end on a hollow column, I, Plate IX., Fig. 9, which conveys the blast from the regulator to the trunnions. The vessel bottoms are removed by means of the hydraulic lifts Y and Y', Fig. 9, and the cars *u* and *u'* which run out laterally into the side pits JJ (see also vv., Plate VII., Fig. 1), under the cranes, so that the bottoms are easily transferred to and from the ovens. To facilitate casting, the ladle, M, Fig. 10, is movable radially on the ladle crane, by means of the screw X and hand-wheel V.

The chief advantages of the American arrangement are, then, first, raising the pit standing up to the general level for convenient and comfortable working; second, making two stories of working room around the vessels; and placing the vessels and their accessories together rather than apart, thus utilizing all the space in the Bessemer building.

In the plant erecting at Bethlehem, Mr. Fritz has gone still farther, and brought the bottom of the pit up to the

general level, so that railway cars from the general level may be run through it in all directions. The standing around the pit is a light structure, raised above the general level at such places as may be required. Mr. Fritz has also worked out a strong and simple plan of horizontal cylinders for rotating the vessels. The cylinders are attached to the vessel-supporting beam before described.

We now return to the general description of the American plant. The gangway on the general level in the cupola building before referred to, AB, Fig. 2, Plate VII., affords a convenient means of ventilation and also of reaching all sides of the vessels, as well as of transporting refractory materials, fuel, etc., into the converting room. Underneath this gangway in the newer works is an underground passage ten feet wide and eight feet in depth (Fig. 5), which communicates with the cellar under the grinding room, and also with the coal-hoist. The débris from the pit is thrown down a chute into wagons placed in this subterranean passage, which when loaded are raised by the lift, which is a very convenient means of removing the waste material, and which is economical both of valuable space and expensive handling. All the water and blast pipes leading from the regulator are secured to the walls of this passage, so that they may readily be examined and repaired. In a cold climate this is indispensable; the pipes cannot be safely buried in the ground.

Notwithstanding all the improvements which have been

made in the American Bessemer plant, until a late date the best practice only produced eight heats per day with two five-ton converters. The reason of this was chiefly owing to the extreme difficulty, in fact, the impossibility, as it seemed, with the refractory materials at hand, of rapidly replacing the bottoms of the converting vessels when the tuyeres were worn too short for further use.

FIG. 1.

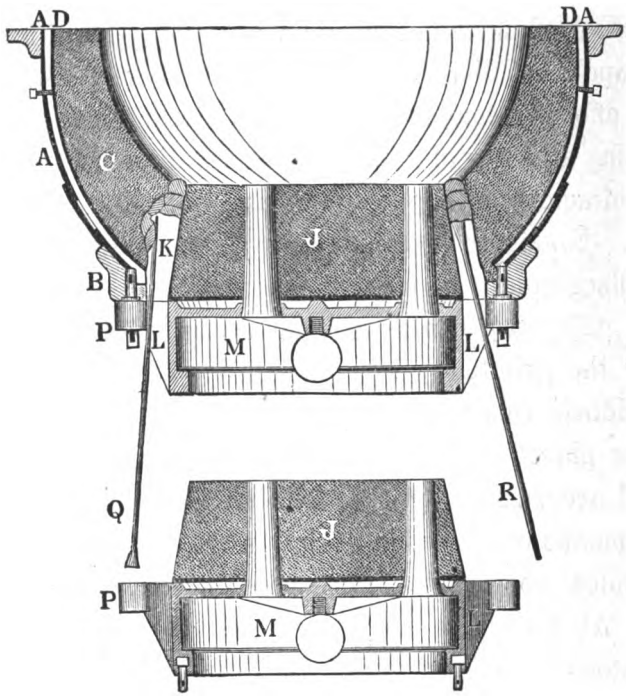


FIG. 2.

This obstacle in the path of making steel manufacture in this country a commercial and mechanical success, has been overcome by an invention of Mr. Holley, by means

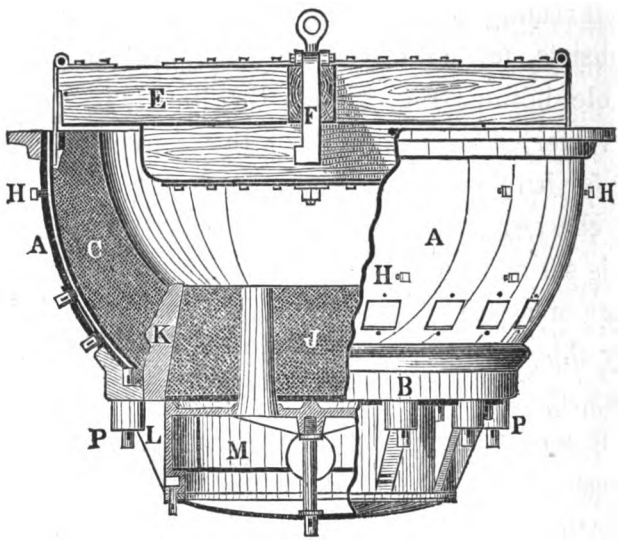
of which the vessel bottoms may be replaced without serious loss of time. As this means of replacing vessel bottoms and making a solid, dry, rammed joint between the bottom of the vessel and its lining has, moreover, been thoroughly tested, and proved to be one of the chief means of greatly increasing the yield of our steel works, it has been thought fully worthy of a detailed description in this memoir.

As will readily be seen from the engravings, the invention consists in making a perfect joint between the removable bottom, Fig. 2, and the lining, C, Fig. 1, of the converter, *from the outside* of the converter, without waiting for it to cool. In from two to three hours after the last charge is made on an old bottom, a new baked bottom is set and heated ready for another charge. One converter of a pair is therefore *always* ready for use, and not only this, but it is in as sound and serviceable condition as if twenty-four hours had been occupied in cooling it and ramming in the bottom from the inside. As a result, from sixteen to twenty five-ton heats are made per day (twenty-four hours) in the American works. Above two thousand tons of ingots have been produced per month at the Troy Works, out of a single pair of five-ton converters, and this with tuyeres which stood only from five to six heats, and with lining material inferior to English ganister. One thousand tons a month was considered a remarkable production before this improvement was adopted. This invention also allows the regular making of both a day and a night turn (twelve heats)

in the Troy two-ton plant, which has only one converter.

The apparatus is very simple, consisting substantially in the arrangement of openings, L, through which the joint may be rammed from without. The converter, the tuyeres and the ganister in which they are imbedded,

FIG. 3.



the tuyere box M, and the ring and cotter bolts, B, Figs. 1 and 3, for holding the bottoms on the converter, are precisely similar to those usually employed. The improvement consists in increasing the diameter of the opening in the lower part of the converter, so as to leave an annular space, L, from three to four inches wide, all around the removable bottom, through which workmen may

look and work. The removable bottom is held to the converter by brackets, P (cast upon tuyere box), which bridge over this annular space, as shown in plan by Fig. 4. When the joint is rammed the plates, N, are

FIG. 4.

cottered on, and make the shell of the converter complete.

The method of operation is as follows: When a set of tuyeres is worn too short for further use, the cotters at P are removed, and the tuyere box and the remaining part of the old tuyeres and bottom are removed by a hydraulic lift under the converter, or by a crane swinging over the converter. Both methods are used at Troy, although a lift and specially adapted car under the

converter are preferable. The converter is then turned on its side; a screen is hung before the opening thus left in the lower part of the converter, to protect the workmen from the heat, and the opening is trimmed out, if necessary, with a long bar, to admit the new bottom. This is done in a few minutes, without inconvenience, while the lining is red hot. A new bottom, Fig. 2, previously rammed and baked in an oven, is then inserted by the lift or the crane, and cottered on. The converter is again turned on its side, and the joint is rammed with plastic ganister by means of the bars, Q R, as shown in Fig. 1. The ganister, mixed with a little fire-clay and wetted so as to be easily moulded by the hand, is formed by the workman into rude blocks of the shape he requires. If the annular space to be fitted is at any point narrow, he forms a wedge-shaped block, inserts it with his hand and rams it home. If the space is wide, he moulds a thin slice of ganister upon either side, with the flat part of his rammer, and then inserts a wedge-shaped slice between them. He begins filling the annular space at the lowest point (the converter then lying on its side, so that the tuyeres stand horizontally); he then moulds the next plastic block upon the side of the one last set, and so on to the top, when the inner edge of the annular space will be completely stopped. The lining being hot, this plastic material will set in five minutes, so that the remaining part of the annular space can then be quickly stopped by ramming in large blocks or balls of ganister; or the inner and outer portions of the annular space

may be filled at one operation, according to the preference of the workman.

There is no difficulty in setting the plastic blocks evenly in the inner edge of the annular space, so as to make the interior of the converter lining continuous and smooth. When, however, the lining is considerably and irregularly worn, a few buckets of "slurry" (semi-fluid ganister and water) may be poured in from the mouth of the converter. A great advantage of the invention is, however, that it avoids the necessity of pouring in a great quantity of water. A "slurry" joint is never solid or trustworthy, and requires a great deal of drying.

The whole operation of inserting the new bottom, ramming the annular space as described, and putting on the covers, N, occupies less than an hour, and has been done in thirty-eight minutes. The time required to trim out the hole and to heat the converter is variable, but need never exceed two hours. Indeed, it is perfectly safe, as far as the bottom is concerned, to omit the heating altogether, as the thin ring of plastic material is thoroughly dried in half an hour by the heat of the lining.

The users of this invention in America state that in no instance has the joint thus formed failed or leaked. The *quality* of the joint is second only to the rapidity of making it.

Another method of ramming the joint is by means of the square openings in the shell of the converter, shown above the ring, B, in Figs. 3 and 4. These may

be used alone or in connection with the openings, L; the latter, however, are sufficient.

The lining of vessels, to be properly done, requires time. The material must be rammed hard and dried slowly. To avoid stopping the works while this is being done, those of the American works which are most advanced in steel manufacture have duplicate upper and lower sections of converters stored away, which have been lined up at leisure in the weigh-house, which is also used as a temporary receptacle for scrap, experimental ingots, etc., and also for piling up ingots in an emergency (Plate VII., Fig. 1). The centre section only of the converters requires to be lined up in place. Where a lining is worn out, the nose and upper and lower sections of the vessel are removed by the lift and car, which have been previously referred to, and the duplicate sections, previously rammed and dried, are placed in position. A lute joint is made between the sections, which, when properly made, is as sound as the rest of the lining.

Blowing Engines.

The American, like the English blowing engines used in the Bessemer process, vary considerably in type. The original Bessemer band air-valve is quickly destroyed in rapid working, and causes much inconvenience and delay, in consequence of which the blast furnace flap-valve, working on a grating with one-inch openings,

has been introduced in its stead, and with much success. The positive air-valve motion has not been introduced in American Bessemer Works. The engines in use at Troy have two fifty-four inch air cylinders, and two forty-two inch steam cylinders, with five feet stroke, and are condensing. They are connected to a common shaft and fly-wheel. These engines are capable of running two five-ton plants without inconvenience. At the Bessemer Works of the Cambria Iron Company, Mr. George Fritz has introduced the Fritz & Moore vertical engine, of the dimensions previously given. Each air and steam cylinder, however, has a separate fly-wheel; the two engines are disconnected, so that only one engine has to be run for heating the vessels, etc., and in case one of them is stopped by an accident, the other is fully capable of running the plant without delay in disconnecting. The use of two independent engines has been adopted in the latest and best American practice.

Hydraulic Apparatus.

The hydraulic machinery in the American Works is a very great improvement over anything used abroad for the same purpose. The Worthington Duplex Pump, with seven-inch water cylinders, and eighteen-inch steam cylinders, at 350 pounds water-pressure to the square inch, is used, and possesses all the advantages of the Cornish engine in the avoidance of a fly-wheel and maintaining a uniform water-pressure. Thus all accidents and consequent delays are avoided.

The cranes have top supports in the roof, instead of bottom supports beneath the cylinders in the foundation. Thus, as will readily be seen, much less lateral strain is brought upon the crane-post, and this form of crane has the additional advantage of being cheaper than the English crane.

Product of the American Plant.

The product in ingots varies in quantity, according to the kind of pig iron treated, but is usually from 84. to 86. per cent. of the pig metal melted.

The product of the five-ton plant at Troy averages above 1,700 tons of ingots per month, and has reached over 2,000 tons per month. The number of heats is usually sixteen per twenty-four hours, although from eighteen to twenty heats per twenty-four hours have been made at the Harrisburg Works. The Works of the Cleveland Rolling Mill Company are now running four five-ton vessels, making twenty-four heats per twenty-four hours, and the five-ton plant of the Union Rolling Mill Company at South Chicago is making sixteen heats per twenty-four hours.*

The quantity of metal usually charged into the converter at each heat is from 12,000 to 12,500 pounds, and the proportion of spiegeleisen which is added at the close of the operation is from 5. to 8. per cent. of the pig

* I am indebted to Mr. A. B. Stone, President of the Cleveland Rolling Mill Company, for the above information concerning the Bessemer plant at Cleveland and South Chicago.

metal charged, according to the nature of the pig iron worked.

The steel is cast in ingots, usually twelve inches square at the base, having a taper of from one to one and a quarter inches, and each ingot of these dimensions is rolled into two rail blooms. In the more recent practice the ingots are twelve by fourteen inches in section, each ingot being rolled into three rail blooms. At the Troy Works, and also at the Cambria Works at Johnstown, the ingots are rolled into blooms of about seven inches square in a three-high train of thirty-inch rolls, and this practice is also to be pursued at the Bessemer Works now in construction at the West. At the Pennsylvania Steel Works at Harrisburg, however, and also at one or two other American establishments, the ingots are hammered into blooms, instead of being rolled.

Apparatus for Rolling Ingots into Blooms.

The blooming mill at the Troy Works, which may be considered a type of the apparatus for blooming ingots used in this country, may be described as follows:

The train, which is three-high, and consists of three rolls, thirty inches in diameter and five feet in length, is driven by a direct-acting engine. The top and bottom rolls do not move vertically, the necks of the middle roll are held by two steel bolsters, which slide up and down in the housings a distance of four inches, and are carried by two six-inch steel screws in each housing. Each

screw has a worm-wheel at the top of the housing, and the four worm-wheels are driven by two worms, on a common shaft. This shaft is driven by belts from the main engine, and is reversed by means of a friction clutch. The whole apparatus is very simple. In front and behind the train are two tables, which are elevated and lowered by a hydraulic cylinder. The rolls have four grooves. The operation of the apparatus is as follows:

The middle roll being elevated to its greatest height, which leaves the opening in the first groove, between the bottom and middle roll, say, eleven inches, a twelve-inch ingot having been placed on the front table, passes through this opening and reaches the rear table, eleven by twelve inches in section. By simply moving a lever attached to the friction clutch, the screw-man then lowers the middle roll, until the distance between the middle and top rolls, at the first pass, is, say, ten inches, and at the same time, by moving a lever attached to a hydraulic valve, he hoists the two tables, and the ingot which then enters the pass is, of course, reduced to ten by twelve inches in section, as it again reaches the front table. The ingot is then lowered and the operation repeated, the ingot being reduced to any desired section at each pass. The ingot is then turned ninety degrees, and passed in like manner through the second groove, and similarly through the third and fourth grooves. The actual reductions of the ingots are as follows: The original size of the ingot being twelve and a quarter

inches square, it is reduced in the first groove, by four passes, to nine and three-sixteenths by twelve and three-eighths inches in section; in the second groove it is reduced to nine and three-sixteenths inches square in section, by four passes; in the third groove, by four passes, to nine and a quarter by seven inches; and in the fourth groove, by five passes, it becomes reduced to six and one-half by seven inches in section. All this work, including the drawing of the ingot from the furnace by hydraulic power, is accomplished in four minutes. The bloom thus made is passed under the steam hammer, and cut into two rail blooms, which are "hot chipped," if necessary, and the remaining end, if sufficiently long, is hammered at the same heat into a billet for the merchant mill. The speed of the blooming mill is about forty-five revolutions per minute. The mill just described has been running continually since early in 1871, without being delayed by accidents, or requiring any extraordinary repairs. The details of the arrangement for moving and holding the middle roll, the tables, guides, guards, and other accessories, are entirely novel, and were worked out by Mr. James Moore, of Philadelphia, by whom the mill was built, and by Mr. A. L. Holley.

The blooming mill at the Cambria Bessemer Works is of the same size as that just described, but instead of the middle roll being moved, the top and bottom rolls are moved by similar means. Mr. George Fritz has made a very ingenious, and partly automatic, addition

to this mill, which consists in driving the feed rolls, and other machinery for moving and turning the bloom on the tables; so that the whole operation of entering the piece and withdrawing it from the rolls is performed by steam-power, and the services of at least five men dispensed with. The blooming mills now being constructed for the North Chicago Rolling Mill Company, at Chicago, and for the Joliet Iron and Steel Company, at Joliet, are being built after the one at Troy, with Mr. Fritz's feeding arrangements added. The blooming apparatus constructing for the Bethlehem Iron Company, at Bethlehem, Pennsylvania, is modeled after that at the Cambria Works.

As has been previously stated, rolling the ingots into blooms is not universal in American Bessemer establishments; yet, with reference to the relative merits of rolling and hammering, it has been settled beyond question, by an extended series of experiments at Troy and Johnstown, that rolling produces a steel of greater uniformity in texture, and of greater ductility. Rolling also saves excessive waste in rail-ends, since rolled blooms, being uniform in section, give equal weights for the same lengths; while hammered ingots vary considerably in section, requiring a maximum allowance for fag-ends. When ingots are rolled into blooms of sufficient size to produce three rails each, greater reduction in section is necessitated, and the homogeneity of the steel is thereby increased.

Bessemer Rail-Trains.

The trains for rolling rails of Bessemer metal are ordinary three-high trains, such as are used in the best American mills, for rolling iron rails, except that they are much heavier. A twenty-one inch train, for rolling seven-inch blooms into rails, in thirteen passes, is divided into three lengths of rolls. A twenty-three or twenty-four inch train is divided into two lengths for the same number of passes, the roughing rolls being five feet in length, and the finishing rolls five feet four inches in length. In the twenty-four inch train being built by Mr. John Fritz, at Bethlehem, a mechanical appliance for feeding the piece into the rolls is being introduced, thus effecting a saving of labor and expense. This mill also involves many other improvements in detail, and will probably, when completed, be the most perfect rolling apparatus in the world.

The product of a steel rail-mill, working on seven-inch blooms, is about 130 tons of rails per twenty-four hours, and a single stand of blooming rolls, like that previously described, when working on ingots sufficiently large to make three rails each, is capable of supplying a rail mill with blooms for this full product.

Quality of Pig Iron Used, and Nature of the Steel Produced.

The earlier Bessemer Works in this country, at first used imported irons and American charcoal irons, but at the present time American mineral coal irons are extensively used. With the gradual development of our mineral resources, consequent upon the increased demand for pig irons adapted to the Bessemer process, many of our ore deposits have been found to produce excellent Bessemer irons when properly smelted with good fuel; besides which the experience acquired in the process renders it possible to use many irons which were formerly not considered suitable. That the irons of the United States are sufficiently pure for the purpose, has already been shown in recent experience at Johnstown and Chicago, and for some years has been fully demonstrated by the success of the Cleveland Iron Works, in the manufacture of Bessemer steel from Lake Superior irons. Besides the Lake Superior deposits, may be mentioned those of Northern New York, Pennsylvania, Ohio, Tennessee, and the immense ore-beds of Missouri, of which the latter, though as yet but partially developed, have been proved to contain some of the purest and richest ores in the world. The complex nature of pig irons, and the injurious influence exercised by certain of the many elements contained in them upon their quality, even when the proportions of those ele-

ments are very minute, renders it difficult to state exactly what amount of them renders the iron unfit for use in the Bessemer process. Some of these defects, however, may be corrected in practice, by mixture with other irons, whose composition is also known by analysis, thus affording to the process a much wider range in the selection of material than it could have without the aid of chemistry. Indeed, it is not too much to say that the process cannot be successfully conducted without the aid of chemical analysis. Experience, supported by chemistry, has shown that there are certain general limits to the proportions of some of the injurious elements found in pig metals, which, if exceeded, will exclude the metal from the list of Bessemer irons. Thus it has been found that a Bessemer iron should not contain more than from 1.5 to 2 per cent. of silicon, although this quantity is necessary to prevent the metal from working too cold in the converter, its oxydation being attended with the evolution of much heat.

The amount of silicon above stated cannot be dispensed with, unless the iron contains a considerable quantity of manganese, which secures a sufficiently hot working. It is possible to use a metal containing a larger proportion of silicon, but the charges are excessively hot, and are consequently liable to cut through the linings of the converters and ladles ; and the waste of iron becomes excessive with so great a quantity of silicon, in addition to which, the steel produced, when alloyed with as much as 0.1 per cent. of silicon, becomes

hard and brittle when cold. On the other hand, the defects consequent upon using a siliceous pig iron are, to a certain degree, compensated for by the fact that rail-ends and scrap, sometimes to the amount of 20. per cent., may be utilized by being melted with the charge of pig metal in the cupola when it is very siliceous. Taking all things into consideration, however, the best results are obtained from pig iron containing a small proportion of silicon, provided the temperature is sufficiently high.

The proportion of sulphur in the pig iron should not exceed 0.1 per cent.; the proportion of phosphorus should not exceed 0.05 per cent., although pig containing as high as 0.08 to 0.1 per cent. of phosphorus has been used with success in some cases. The new methods of determining phosphorus are much more accurate than those formerly employed. The old rule was that 0.02 per cent. of phosphorus unfitted the iron for Bessemerizing. By the modern methods of analysis, however, the same irons are shown to contain from 0.05 to 0.1 per cent. As no improvement in the process has rendered more phosphorus admissible, the probable reason why irons containing more of this element appear to be used successfully, is that, in the old practice, only a part of what really existed in the irons was determined. Care should be exercised in the selection of the fuel and limestone with which the pig irons are smelted, as well as in selecting the fuel used in the cupola, since the former contains sulphur and phosphorus to a greater or less extent, and

an excess of flux has been found, under certain conditions of working, to cause some calcium to be reduced and alloy with the iron, rendering the steel produced cold-short.

Steel intended for rolling into boiler-plate and other purposes, for which a low steel, or rather homogeneous metal is required, should contain from 0.15 to 0.20 per cent. of carbon. Steel which is intended for rails should contain 0.35 to 0.45 per cent. of carbon, to secure good wearing qualities. Railway managers, however, in the majority of cases, insist upon having soft steel rails, even at the expense of greater duration of wear, in order to avoid all risk of fracture; and hence it has become customary, in consequence of the restrictions thus imposed, to manufacture rails containing 0.25 per cent. of carbon. Although the life of a steel rail of moderate hardness may be fairly estimated to be about thirty years, yet it will eventually be found that the soft steel rails now largely in use will not last so long. Indeed, the writer has seen some Bessemer steel rails on a trunk-line, which, after some two or three years' exposure to heavy traffic, had actually begun to yield to the pressure, owing to the fact that the steel of which they were made was too mild.

The effect of wear upon soft steel rails is somewhat peculiar, and may be said to resemble a wave of steel flowing from the centre of the head of the rail to either side, where it subsequently becomes detached in thin scales. This phenomenon, which is simply owing to a

lack of carbon, has been by some confounded with lamination, which is a term not applicable to Bessemer steel rails, which are homogeneous in their nature, and contain no welds. This term should be used in connection with the wear of iron rails only; it consists in the imperfect weld of the head being discovered by the continuous blows from the wheels of passing trains, and eventually causing the head of the rail to strip off to a greater or less extent.

There are also two other qualities belonging to steel which are often confounded, but which are nevertheless totally distinct. These are cold-shortness and hardness. A very small proportion of phosphorus or silicon, or a very large proportion of carbon, for instance, 1. per cent., will produce cold-shortness in steel rails; but experiment has shown that a sound rail, containing 0.5 per cent. of carbon and only a trace of phosphorus or silicon, has withstood all the standard tests of ductility when cold. If the pig irons used are impure, the carbon must be completely removed in the converter, but if the pig irons do not contain more than a trace of phosphorus, or more silicon than has been previously stated to be desirable for successful working, the steel will not be cold-short if it contains a greater proportion than 0.25 per cent. of carbon. From this we must draw the conclusion that impure steel will not admit of being highly carburized without becoming brittle.

METHODS OF TESTING THE PRODUCT.

In some of the American Works the carbon contained in the steel from every cast is determined by the Eggertz method; and very thorough and reliable tests of a mechanical nature are also employed in conjunction with the chemical test. At the Troy Works, and some others, the chief dependence is placed upon mechanical tests alone, which require the almost exclusive attention of an experienced scientific expert, assisted by a blacksmith and helper, having a distinct complement of tools and appliances. The method of conducting these tests is as follows:

A bar three inches square in section is made by hammering the end of a rolled rail-bloom. This is placed under a seven-ton steam hammer, upon supports twelve inches apart, and a round piece of steel, three inches in diameter, is placed on the bar at its middle point, to concentrate the effect of the blow. The ram is now allowed to fall on the piece from a height sufficient to bend it a distance of from one-quarter to three-eighths of an inch, when the piece is reversed and the ram again falls upon it from a height sufficient to straighten it. If the test-piece fails to withstand the reverse blow, the entire cast corresponding to it is laid aside, to be rolled into second quality rails. The test-piece is frequently reversed two or three times, and if the result proves the steel corresponding to it to be too soft for good wear as rails, it is used for other purposes, and the blowing of subsequent charges is regulated accordingly.

This test more nearly resembles that to which the steel is subjected when placed in the track, and is, therefore, superior to the usual test prescribed by railway managers, which consists in allowing a small weight to fall from a great height upon a finished rail. Besides the tests just described, very thorough physical and mechanical tests are also made by means of hardening, welding, bending cold and hot, etc., for which test a bar three-quarters of an inch in section is forged from the test-ingot of each heat.

General Description of the Bessemer Works in the United States now Running and under Construction.

The first successful Bessemer Works was started in February, 1865, at Troy, New York. The plant consisted of a one and one-half ton converter, and hand-cranes and reverberatory melting furnaces. The Troy five-ton plant was put in operation in the Spring of 1867. In the meantime, a small experimental converter was erected and worked at Wyandotte, Michigan, but this has since been suspended. In the Spring of 1867, a pair of five-ton vessels were put in operation at Harrisburg, Pennsylvania, and in the latter part of the same year a similar plant was inaugurated by the Cleveland Rolling Mill Company, at Newburg, near Cleveland, Ohio. The Cleveland Rolling Mill Company now has a second five-ton plant in operation, and the Pennsylvania Steel Company is about erecting an additional five-ton plant.

The Troy Works, having been burned in the autumn of 1868, were rebuilt, and again started in January, 1870. In this rebuilding, the improvements which have led to the large product of the American Bessemer plant were fully developed. These improvements, which have been previously discussed in detail in this memoir, consist chiefly in the cupola practice and the method of replacing vessel bottoms, together with the previously described arrangement of the pit, cranes, vessels, and other accessories, have been introduced into nearly all the American works now running, or being built, and are chiefly covered by the patents of Mr. Alexander L. Holley, whose name has been identified with Bessemer steel in this country from its introduction until the present time. The improvements mentioned were first developed in detail by Mr. Holley, when building the Troy and Harrisburg Works, and have since been modified in the newer works which he is now building.

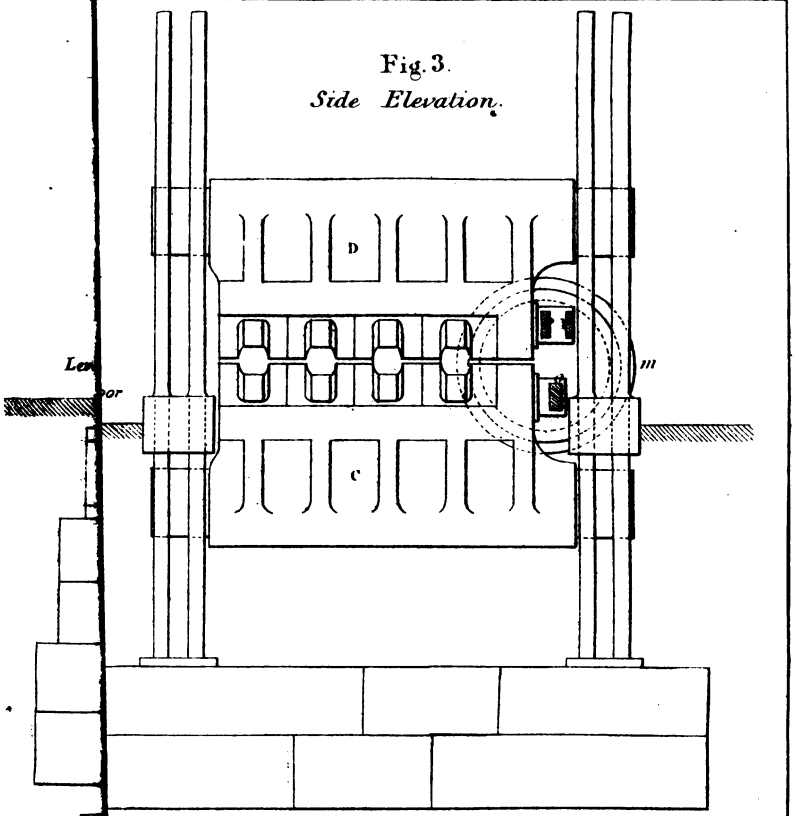
In addition to those already mentioned, a pair of five-ton vessels have been put in operation at Bridgeport (South Chicago) during the past summer, by the Union Rolling Mill Company; also the five-ton plant erected by the Cambria Company, which is, thus far, the most complete plant in the world, was also started at Johnstown, Pennsylvania, at about the same time. There are also several works now in process of construction which will soon be in operation. These are the five-ton plant being built at Bethlehem, Pennsylvania, by the Bethlehem Iron Company; the five-ton plant of the North Chicago Roll-

ing Mill Company, at Chicago, and the similar plant of the Joliet Iron and Steel Company, in course of construction at Joliet, Illinois. These works will all be in full operation, probably, during the first half of the year 1872.

These are the only Bessemer works now being built, or in operation, although other works are projected both in the East and the West.

The perfection to which the Bessemer steel manufacture has been brought in this country, has been reached by slow and expensive steps, since sudden revolutions are impossible in any department of the metallurgy of iron and steel. The difficulties which have been overcome, the obstacles successfully contended against, and the vast number of experiments tried, have caused the outlay of great sums of money, with no immediate prospect of return in the majority of cases. The chief burden of these expenses has been borne by Messrs. John A. Griswold & Co., of Troy, to whom is due, in great measure, the present status of the Bessemer interest, as well as the credit of first introducing the process into the United States.

Fig. 3.
Side Elevation.



Section of Steam Cylinder.

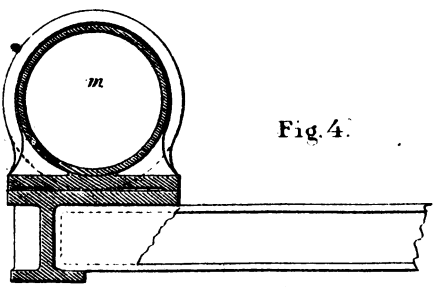
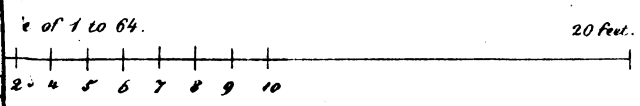


Fig. 4.



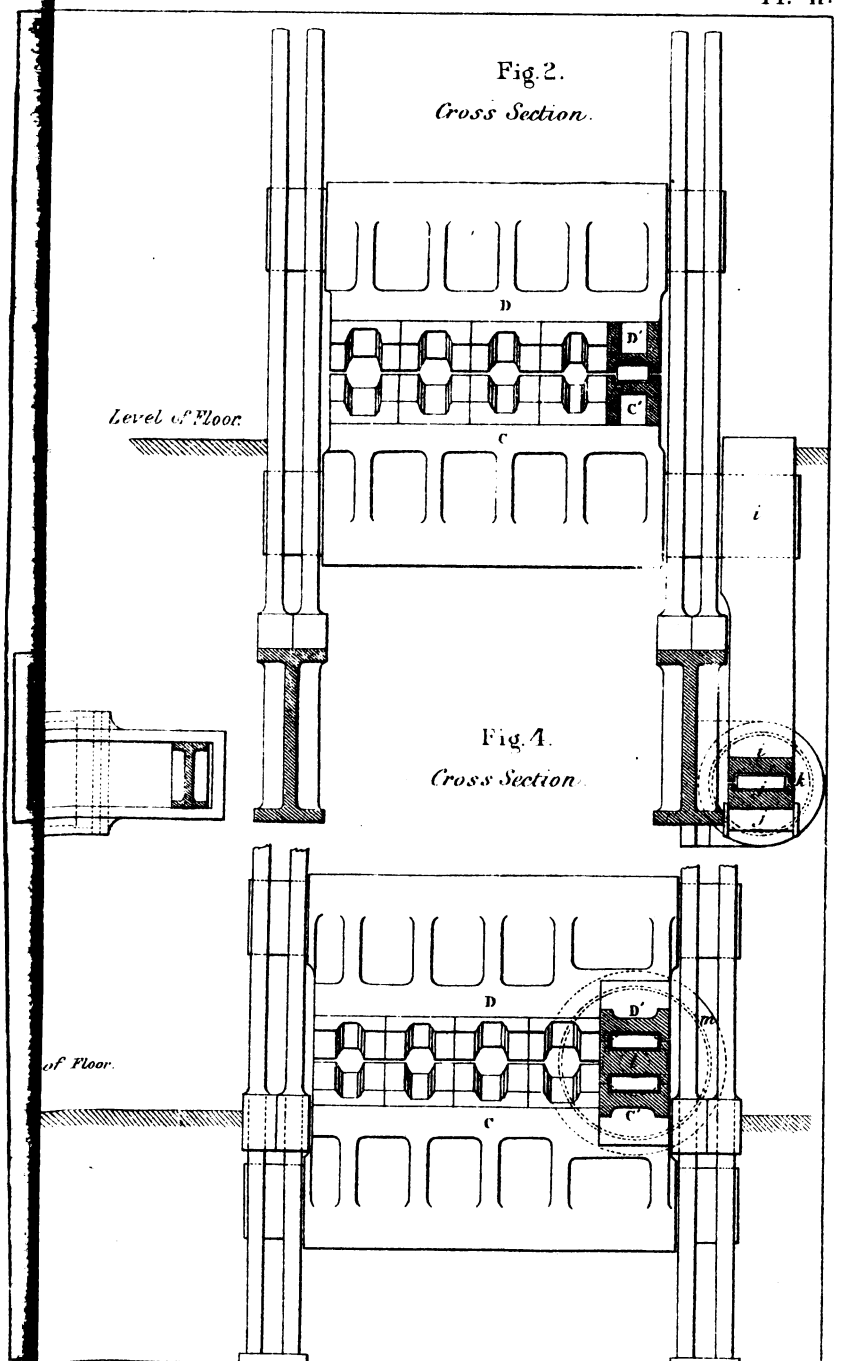
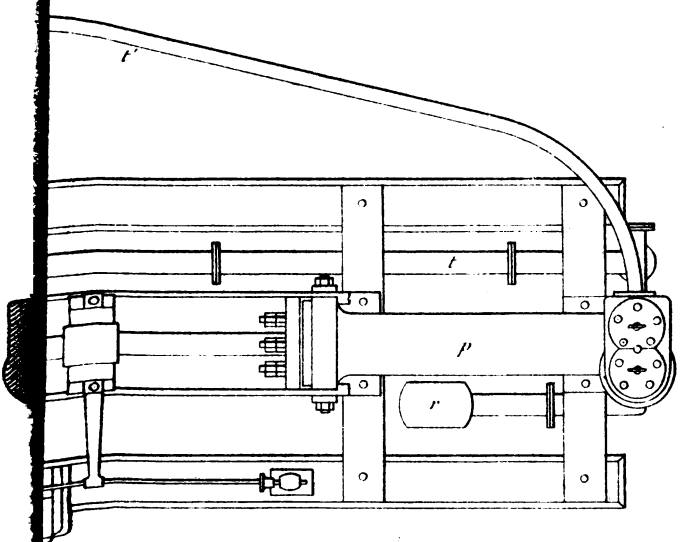


Fig. 2.
Cross Section.
D
D'
C'
C
Level of Floor
i
Fig. 4.
Cross Section.
k
h
l
D
D'
C'
C
of Floor.

V IENNA



MER'S FORGING PRESS

Fig. 3.

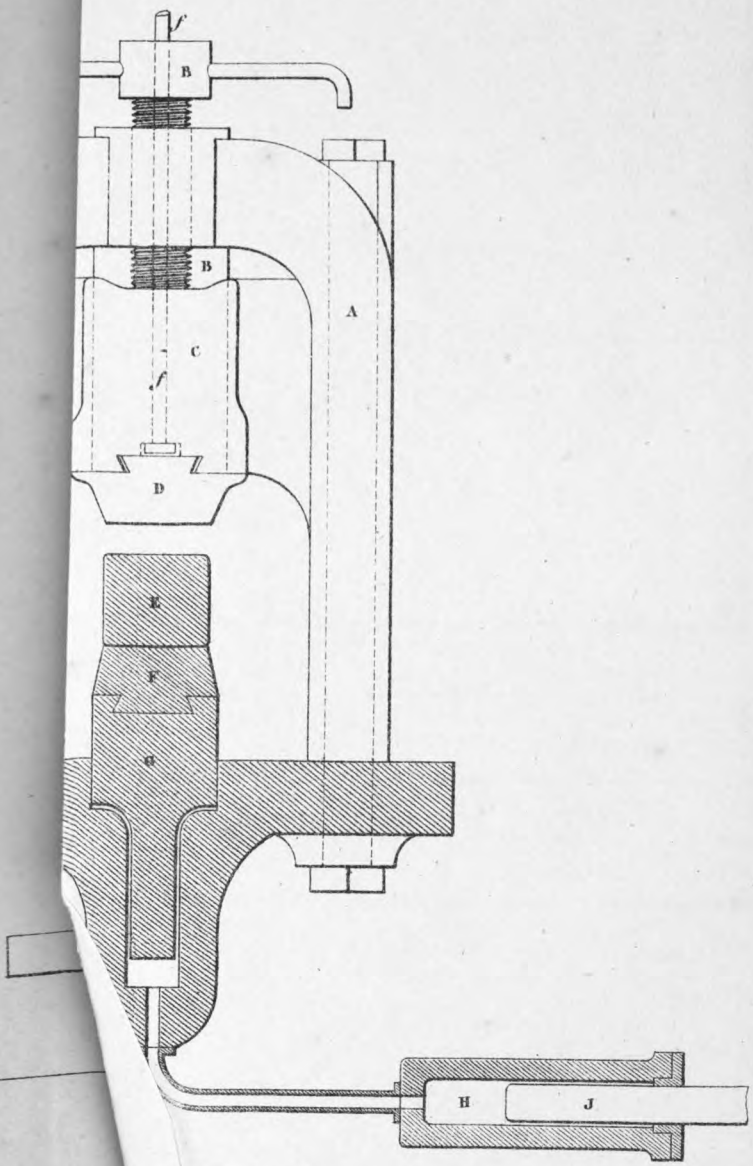


Fig. 3.
Cross Section on V. V.

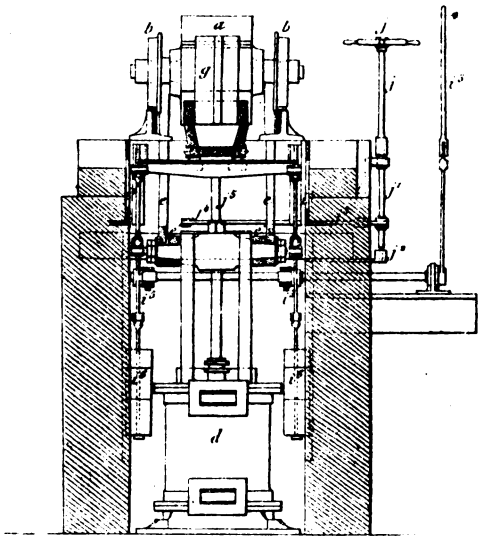


Fig. 4.
Cross Section on X.Y.

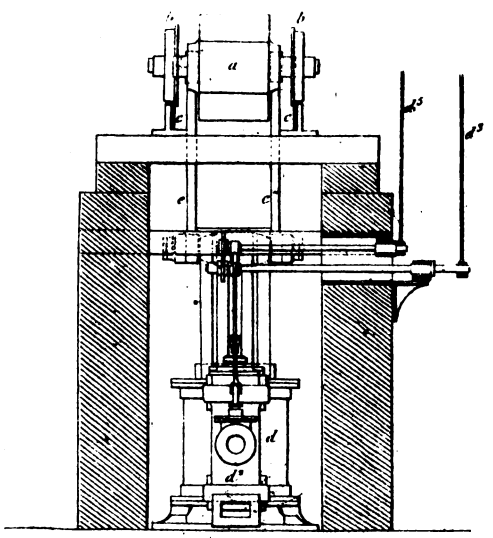


Fig. 4.
ection on X. Y.

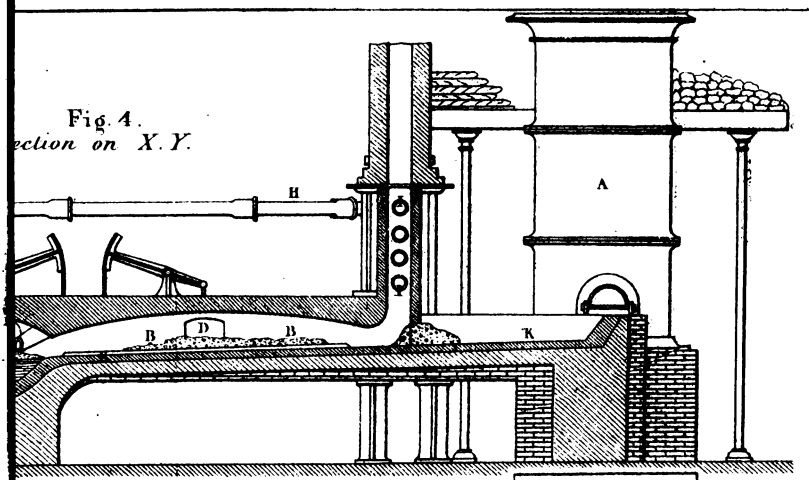
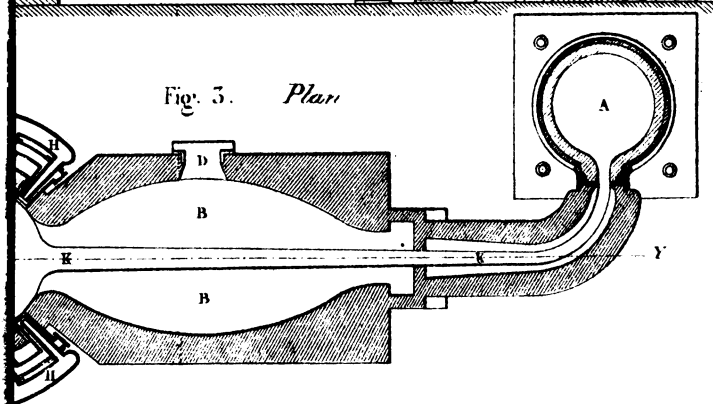
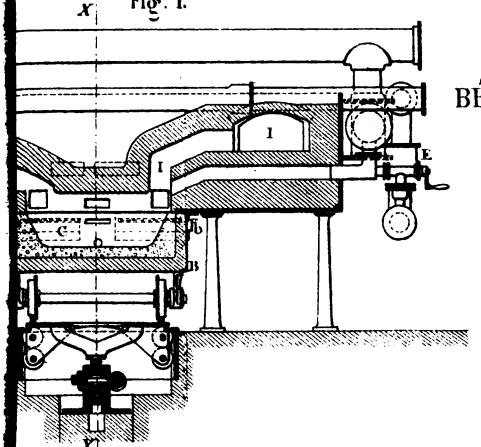


Fig. 3. *Plan*



X Fig. 1.

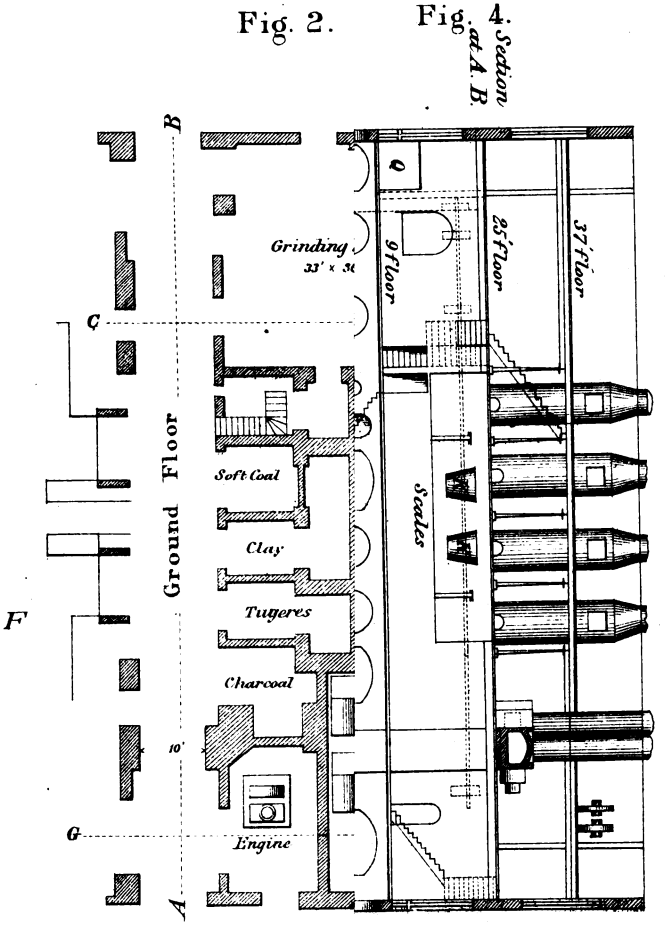


BÉRARD'S STEEL FURNACE

(Fig. 1. and 2.)

Fig. 2.

Fig. 4.


Section at A. B.
B
C
F
G
A
Ground Floor
Grinding
33' x 30'
Soft Coal
Clay
Tugeres
Charcoal
10'
Engine
Q
9 Floor
25 Floor
37 Floor
Scales

STANDARD ENGLISH PLANT.

Fig. 7.

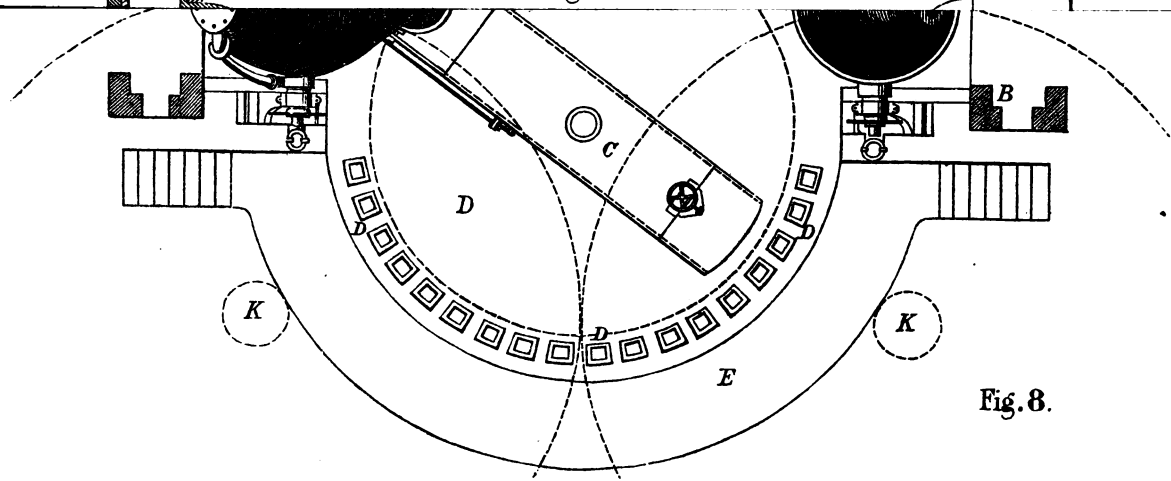
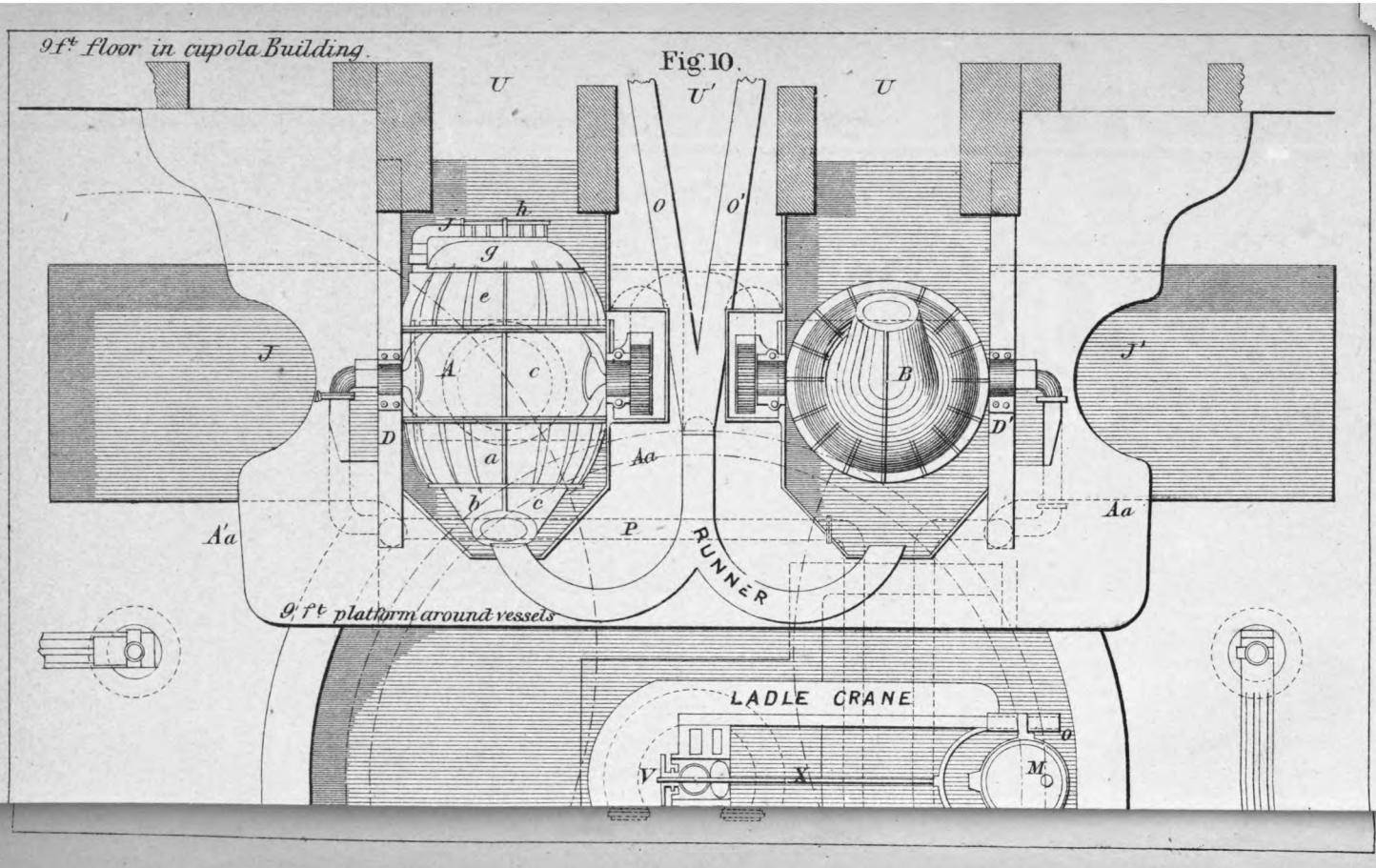


Fig. 8.

Pl. VIII.

Pl. IX.


9ft floor in cupola Building.
Fig. 10.
U
U'
U
o
o'
h
f
g
e
J
J'
A
c
B
D
D'
a
Aa
b
c
A'a
P
RUNNER
9 ft platform around vessels
LADLE CRANE
V
X
M
O

B89074783556A